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Field Trip No. 1

GEOLOGY OF THE APPALACHIAN HIGHLANDS OF EAST-CENTRAL NEW YORK, SOUTHER VERMONT, AND SOUTHERN NEW HAMPSHIRE

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GEOLOGY OF THE APPALACHIAN HIGHLANDS OF EAST-CENTRAL NEW YORK, SOUTHERN VERMONT, AND SOUTHERN NEW HAMPSHIRE

By Marland P. Billings, John Rodgers, and James B. Thompson, Jr.

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Introduction

In planning a trip to study the bedrock geology of eastern New York, New Hampshire, and Vermont, the authors had to make several difficult decisions. One proposal was to make one or two trips to relatively small areas that would be studied in great detail. It was finally decided, however, that the most instructive trip would be one that went all the way across the northern Appalachians, from the foreland on the west to the Atlantic Ocean on the east. Although a more northerly route would have been more advantageous in some ways, especially in New Hampshire, it was finally decided to take a more southerly route. One disadvantage of such a long trip, of course, is that the participants will, at the best, get only a superficial view of the geology. Relatively few stops can be made and many especially good localities can not be visited because they are too far from the main routes of travel. Localities that are accessible to five-passenger automobiles cannot be reached by large busses. Nevertheless, the trip should serve as a good framework into which the serious student can properly place the papers describing small areas.

The geological map (Pl. 4) accompanying this guide is not merely a compilation of published papers. It represents a synthesis upon which the authors have been working for several years. Moreover, the map incorporates a great deal of unpublished information that many geologists have kindly contributed; due acknowledgment is given in the next section of this paper. The authors believe, therefore, that the map is a major contribution to the geology of the northern Appalachians.

In preparing Plate 4 the authors were faced with a dilemma. A map attempting to show the stratigraphy, plutonic rocks, differences in the grade of metamorphism, as well as cultural features, would be so crowded that the geological pattern would be effectively concealed. Inasmuch as the chief function of Plate 4 is to show the stratigraphy and structure, the authors reluctantly decided that only a minimum number of cultural features could be shown. Only the principal municipalities are indicated. But in order to provide some sort of guide to the reader the area is divided into 15-minute quadrangles by latitude and longitude lines. A coordinate system along the margin of the map makes it possible to refer to individual quadrangles by letters and numbers, such as D4. Topographic or geologic maps of quadrangles may be used for precise location and the details of the geology. Plate 1 is an index map of all the topographic maps, issued by the U. S. Geological Survey, available for the area covered by Plate 4.

Plate 4, like all geological maps, should be considered a progress report. Although in many parts of the area the authors are reasonably well satisfied with the interpretation of the stratigraphy and structure, in some places there is more than one possible interpretation. In preparing a map it is necessary to adopt one of these interpretations as the most probable. It is felt that many of these problems can be resolved within the next decade by intensive work.

Acknowledgments

Much of the information incorporated into Plate 4 has been compiled from published reports. The principal sources of such data are shown in Plate 2 and the papers are listed in the bibliographies. The writers are especially indebted, however, to those many individuals and organizations who have permitted use of hitherto unpublished information. Although due credit is indicated in Plate 2, it seems only proper that special mention of these contributors should also be made here.

Rodgers, who is responsible for the compilation of the map of east-central New

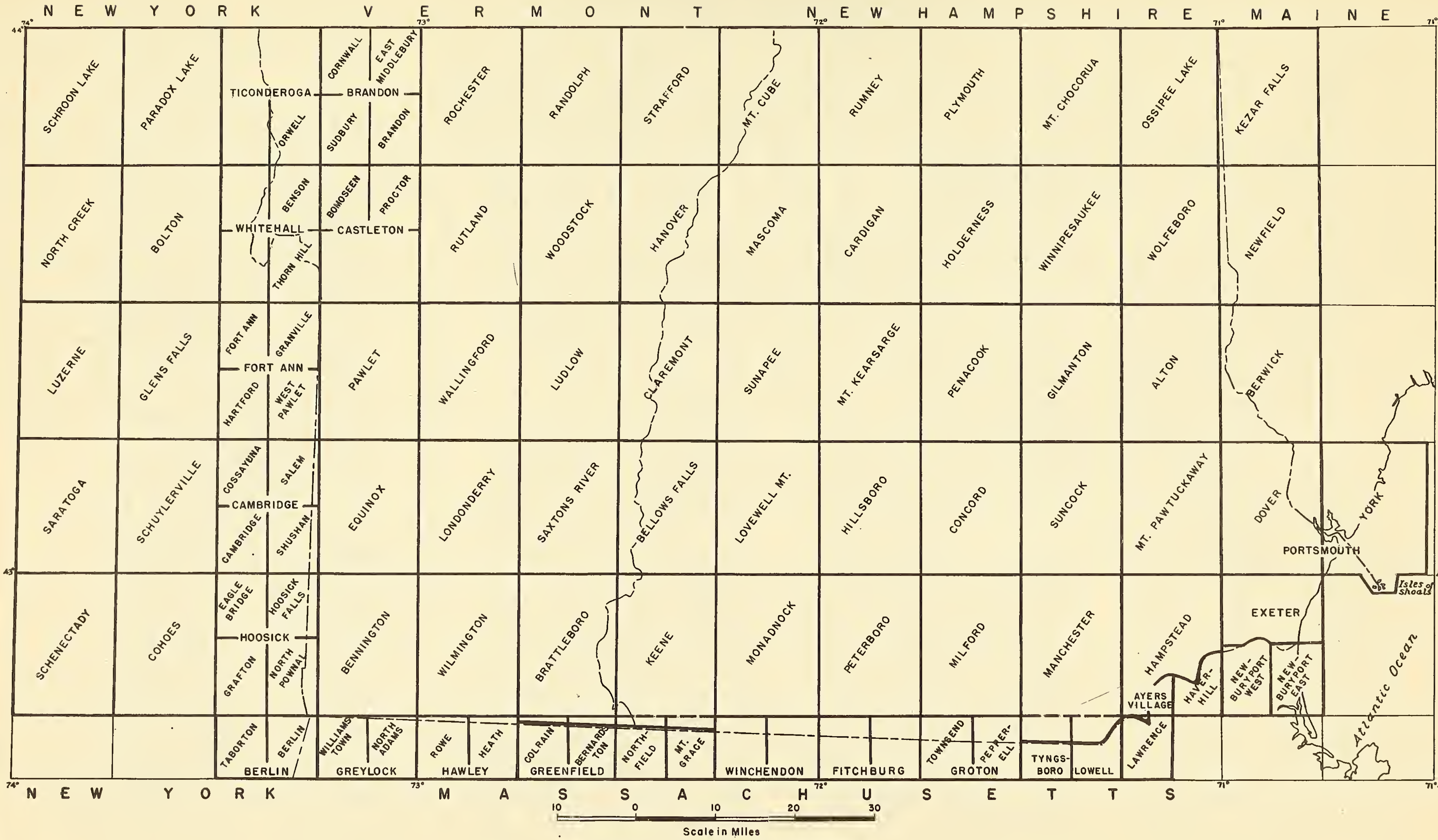

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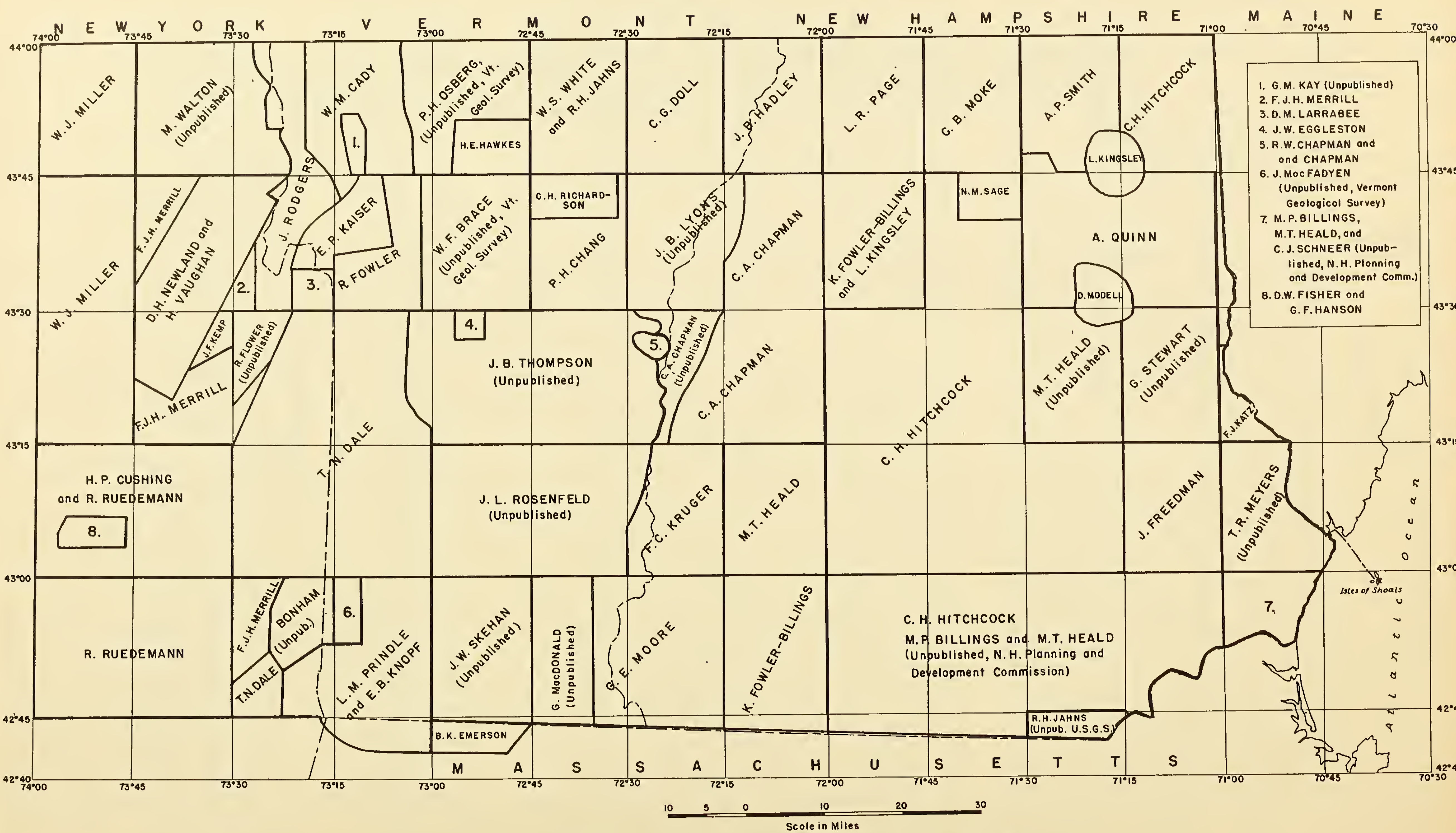
Plate I



SOURCES OF INFORMATION FOR GEOLOGICAL MAP, PLATE 2

York and parts of western Vermont, wishes first to acknowledge the generosity of R. H. Flower in providing the material for the hitherto-unpublished section around Fort Ann, New York, and for that part of the map. If this section has been misrepresented here, however, Rodgers must take full blame. The manuscript of the text describing the geology of eastern New York has also been greatly improved as a result of discussion and correspondence with Flower on the subject. Permission to review and use unpublished maps and manuscripts was kindly given by Lawrence D. Bonham (map and text covering Hoosick Falls, New York, area), Marshall Kay (map of area around Sudbury, Vermont), and Matt S. Walton (map of Paradox Lake quadrangle and part of Ticonderoga quadrangle, New York). Winifred Goldring, State Paleontologist, and John G. Broughton, State Geologist, of New York, kindly made available material in the files of the New York State Science Service and also criticized the map and manuscript as it applied to eastern New York.

Thompson, who is responsible for the compilation of the map of southern Vermont, acknowledges the kindness of the State Geologist of Vermont, Charles G. Doll, who permitted the use of the following unpublished work done in part under State auspices: East Middlebury and northern half of the Rochester quadrangle, by Philip H. Osberg; Rutland quadrangle, by William F. Brace; and part of the Bennington quadrangle, by John MacFadyen. The geologists who did this work have also graciously given permission to use their data. In addition, the following have granted permission to incorporate their unpublished maps; Wilmington quadrangle, James W. Skehan, S. J.; Saxtons River quadrangle and parts of Londonderry and Bellows Falls quadrangles, John L. Rosenfeld; Hanover quadrangle, John B. Lyons; southern two-thirds of the Woodstock quadrangle, P. H. Chang; western two-thirds of the Brattleboro quadrangle, G. J. F. MacDonald; Vermont part of Claremont quadrangle, C. A. Chapman; Vermont part of Greenfield quadrangle and Green Mountain front in Equinox and Bennington quadrangles, Fred Barker.

Billings, who is responsible for southern New Hampshire, gratefully acknowledges the use of the following unpublished maps: Hanover quadrangle, John B. Lyons; northeastern part of the Holderness quadrangle, N. M. Sage; Wolfeboro quadrangle, Alonzo Quinn; Claremont quadrangle, C. A. Chapman; Alton quadrangle, Glenn W. Stewart; and Dover quadrangle, T. R. Meyers. The State Geologist of New Hampshire, T. R. Meyers, has also permitted the use of the following mapping done under the auspices of the New Hampshire Planning and Development Commission: Gilmanton quadrangle, by Milton T. Heald; a reconnaissance survey of a large area in southern New Hampshire by M. P. Billings and M. T. Heald (see Plate 2). Cecil J. Schneer also contributed information for the Exeter quadrangle. The U. S. Geological Survey has permitted the use of R. H. Jahns' unpublished maps of the New Hampshire parts of the Tyngsboro and Lowell quadrangles.

General Geological Features

In the area covered by Plate 4 the bedrock ranges in age from pre-Cambrian to Mississippian (?), except for a few mafic dikes of Triassic age that are too small to show. The original sedimentary and volcanic rocks, most of which are now metamorphosed, are pre-Cambrian, Cambrian, Ordovician, Silurian, Devonian, and Mississipian (?). The plutonic rocks are pre-Cambrian, mid-Ordovician (?), late Ordovician (?), middle and late Devonian (?), and Mississippian (?).

The grade of metamorphism differs greatly throughout the area; the metamorphic zones are shown on Plate 3. Because of the progressive change in the grade of metamorphism the lithology and mineralogy of a rock of given chemical composition may differ from one place to another. For example, an original shale may appear as at least five different rocks, depending upon the grade of metamorphism: (1) slate; (2) phyllite with biotite porphyroblasts; (3) phyllite with biotite and garnet

METAMORPHIC ZONES IN EAST–CENTRAL NEW YORK, SOUTHERN VERMONT AND SOUTHERN NEW HAMPSHIRE

Plate 3

porphyroblasts; (4) biotite-garnet-staurolite schist; and (5) biotite-garnet-sillimanite schist. The description of the lithology of some of the formations is thus greatly complicated by differences in metamorphism. Whereas in an area of unmetamorphosed sediments one description of the lithology will generally suffice, in an area such as New England the lithology of a single formation may have to be described five times.

On the basis of key index minerals, best displayed in rocks of original argillaceous composition, the rocks may be assigned to five metamorphic zones - the chlorite, biotite, garnet, staurolite, and sillimanite zones. For those who prefer the facies classification it may be stated that the chlorite zone is the same as the chlorite-muscovite subfacies of the green schist facies; the biotite zone is the same as the chlorite-biotite subfacies of the green schist facies; the garnet zone is the same as the chloritoid-almandite subfacies of the amphibolite facies; and the sillimanite zone is the same as the sillimanite-almandite subfacies of the amphibolite facies.

On Plate 4 the formations are indicated by different patterns. The grade of metamorphism is shown on Plate 3. The lithology for each formation is given in tables in the text. Thus to determine the lithology at any given place it is first necessary to find out the name of the formation from Plate 4. Then by reference to Plate 3 one determines the metamorphic zone. The lithology is then found by reference to the appropriate table.

As shown on Plate 3 the rocks of the foreland may be classified as unmetamorphosed. From here the metamorphism increase easterly, attaining the staurolite zone in central Vermont. Still further east the metamorphism decreases, falling to the chlorite zone along the Connecticut River. Further east it increases, and the rocks in much of central New Hampshire are in the sillimanite zone. In southeastern New Hampshire the metamorphism decreases rapdily and in much of this area the rocks are in the chlorite or biotite zone. Finally, just east of Portsmouth, the rocks are again in the sillimanite zone.

As can be seen from Plate 4, the structural grain in this part of the Appalachian Highlands trends north - south or northeast-southwest.

The principal times of deformation that have affected this area are: (1) pre-Cambrian; (2) mid-Ordovician (uplift and transgression); (3) Taconic (late Ordovician); and (4) Acadian (middle and late Devonian). There is no evidence that the Appalachian revolution (late Paleozoic) played an important role.

EAST - CENTRAL NEW YORK AND PARTS OF WESTERN VERMONT

By John Rodgers

Region of Flat-lying Paleozoic Rocks

General. West of the belts of Paleozoic folding that comprise the New England province of the Appalachian Mountain system is a region in which the Paleozoic rocks still lie for the most part practically horizontal, the eastern edge indeed of the great Central Stable region of the North American continent. The part of this region here considered is by no means undistrubed, but what disturbance it has undergone since pre-Cambrian times has been almost entirely high-angle block faulting, with a little accompanying drag folding. On the uplifted blocks the pre-Cambrian basement of the stable platform has been brought to view; on the depressed blocks a relatively thin sequence of Cambrian and Ordovician sedimentary rocks, mainly carbonate rock but with sandstone below and shale above, has been preserved. The pre-Cambrian

rocks uphold the Adirondack Mountains; the Paleozoic rocks underlie the low ground adjacent.

In general, this region is sharply set off from the next belt east, the westernmost belt in which the rocks show Paleozoic folding and thrust faulting; the boundary between is marked for much of its length by faults. Across the southern half of the area covered by the accompanying map (Plate 4) this boundary follows the presumably faulted contact between the relatively undistrubed Canajoharie shale and Schenectady formation on the west and the highly deformed Snake Hill shale or slate on the east (all Middle Ordovician); it passes just east of Schenectady, New York (E1)*, and probably under Saratoga Lake. Approaching Fort Ann, New York (C3), Lower Ordovician carbonate rocks appear on both sides, being folded on the east but nearly flat-lying on the west; from Fort Ann north past Whitehall, New York (B3), to Bald Mountain in Vermont (just north of Whitehall), folded Cambrian rocks on the east are in contact with pre-Cambrian gneiss on the west along what is probably a normal fault (crossed between Stops 3 and 4, and again at Comstock village). Farther north, the boundary can be traced within the Cambrian and Ordovician rocks, following a normal fault but apparently offset by two or three transverse strike-slip faults; finally in Vermont, east of Ticonderoga, New York, it is lost in a wide expanse of Canajoharie or Snake Hill shale covered by late-glacial lake and marine clay, the shale being mostly flat-lying along Lake Champlain but highly crumpled farther east.

The present trip lies in this region for only a short distance, from near Smith Basin (beyond Stop 2), to beyond Fort Ann (nearly to Stop 4).

Stratigraphy. Table 1 gives geologic sections in this region, in the vicinity of Saratoga Springs and of Ticonderoga, New York. The pre-Cambrian rocks are displayed at and just beyond Stop 3, north of Fort Ann. The rocks of the next belt east, seen at Stops 2 to 8, are much like those in this region.

Structure. The structure of this region is dominated by large high-angle faults (normal where the dip has been determined), mostly trending northeast or north; these characterize the entire southern and eastern border of the Adirondack Mountains. In general, the separate mountain ranges are separate fault blocks. The faults are mainly downthrown on the east, but there are exceptions, notably southeast of Lake George (B2) (it is not known that the exceptional faults are normal). In the Champlain Valley, the high-angle faults trending north are accompanied and apparently offset by a few east-west strike-slip faults.

The age of these faults relative to the folding and faulting in the belts to the east is not certain. Swinnerton (1932), Megathlin (1938), and Kay (1942) have suggested that the normal faults are later, Quinn (1933) that they are earlier, and Rodgers (1937) that they are of the same general age as the deformation to the east. The normal faults and their accompanying strike-slip faults cut at least some of the eastern folds and faults in the area north of Whitehall, New York (B3); on the other hand, the folding in this same area terminates abruptly at the normal fault marking the boundary between the two belts, as though the Adirondacks buttress had already been blocked out. The problem is still open.

The Canajoharie shale at the east edge of the "undistrubed" region shows some crumpling and slaty cleavage both near Saratoga Lake (D2) and along Lake Champlain (A3). At Hudson Falls, New York (C2), and again a few miles north of Ticonderoga, New York (A3), virtually horizontal unfolded shale displays prominent slaty cleavage dipping 35° to the east.

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* Refers to coordinate system on Plate 4.

Western Belt of Deformed Carbonate Rocks

General. From a few miles south of Fort Ann, New York (C3), north into the Champlain Valley, the westernmost belt of the deformed New England province consists chiefly of folded and thrust-faulted Cambrian and Ordovician carbonate rock, the sequence being similar to, though thicker than, the sequence in the flat-lying rocks to the west. South of Fort Ann, however, the carbonate rock disappears under stratigraphically higher shale (the Snake Hill shale), also highly deformed, which forms most of this belt southwestward across the area shown on the accompanying map.

Most of the eastern boundary of this belt is marked by a major thrust fault, beyond which is a much more slaty sequence of rocks, underlying the Taconic Mountains along the eastern boundary of New York State. Northward the Taconic mass of slate comes to an end at Government Hill in Sudbury town, 5 miles west of Brandon, Vermont (See Table 4; description of eastern carbonate sequence), and the eastern boundary of the belt is no longer sharply marked, for the carbonate rocks to the east, at the west foot of the Green Mountains, exhibit the same general sequence, though changed in detail and including a thick Lower Cambrian succession beneath (see below description of eastern belt of deformed carbonate rocks). For convenience the boundary between the two belts is here taken along the west edge of the nappe-like mass around Sudbury, then along the trough of the syncline of Middle Ordovician slate that separates the outcrop belts of the two carbonate sequences, and finally along the thrust fault next west of Cornwall, Vermont (A4); this fault increases rapidly in throw northward and becomes the major Champlain fault, which can be traced from here north to the Canadian border (45°N. latitude). Apparently it dies out southward, however, either under a drumlin west of Cornwall or in the slate in the trough of the syncline south of Cornwall (the latter interpretation is accepted on the accompanying map).

The route of the present trip lies mainly in this belt from Albany to Stop 9 lying on one or the other side of the fault at the east edge as far as Argyle (D3), then crossing the belt diagonally where it is all shale to Stop 2, and finally criss-crossing the carbonate rocks from Stop 4 to Stop 8.

Stratigraphy. Table 2 gives geologic sections in this belt, in the vicinity of Fort Ann, New York, and of Shoreham, Vermont. Stops 2 and 4 to 8 display several of the formations in the Fort Ann sequence.

Gray and pinkish dolomite with red silty partings appears in the core of an anticline of the Danby formation northeast of Shoreham, Vermont (A3); perhaps this represents the Winooski dolomite of the eastern carbonate sequence. In West Haven town, however, 7 miles north of Whitehall, New York (B3), pre-Cambrian gneiss is exposed under dipping Potsdam (Danby) quartzite on the east side of the normal fault separating folded from flat-lying Paleozoic rocks. Otherwise the base of the section is not exposed within this belt.

South of Fort Ann, New York (C3), the Snake Hill shale covers the carbonate rocks; it consists of 3,000 feet or more of bluish gray shale, partly sandy and silty, with many thin sandstone, sandy limestone, and "crystalline" limestone layers (Cushing and Ruedemann, 1914). Set in this shale mass, from near Schuylerville, New York (D2), southward, are large lenticular masses of older slate belonging to the Taconic sequence next east, with which the rocks they contain are described. Carbonate rock of the western sequence reappears, however, in a narrow slice at least 5 miles long along the thrust fault forming the eastern margin of the Snake Hill belt opposite Schuylerville (to be seen at Bald Mountain, Stop 1). These rocks are limestone and cherty dolomite and contain Lower Ordovician fossils.

Dale (1899) maps a similar slice near Argyle (D3), a few miles to the northeast.

Similar limestone occurs as inclusions in the igneous rock of Starks Knob, a solitary mass close to Schuylerville (D2). The igneous rock is glassy amygdaloidal olivine basalt; it forms ball-like masses that may be pillows. It is as badly sheared and deformed as the enclosing (Normanskill) slate, part of one of the Taconic slate masses mentioned above. Perhaps it represents a sheared remnant of a lava flow laid down among the shales and deformed with them. The limestone inclusions pose difficult problems, however.

Structure. The western carbonate belt is characterized by thrust faults and also in most areas by folds. Where the Upper Cambrian and Lower Ordovician part of the section is exposed, the folds are fairly open and there is generally only one thrust fault, which is of large displacement. The main fault near the north edge of the area shown on the accompanying map, the Orwell thrust of Cady (1945), brings the lower part of the carbonate sequence over Snake Hill or Canajoharie shale, which extends west to Lake Champlain. Northward this fault disappears under the Champlain fault a few miles north of the map boundary, but southward it diverges from the Champlain fault. About 3 miles southwest of Orwell, Vermont, or about six miles southeast of Ticonderoga, New York (A3), it meets intersecting high-angle faults and cannot be traced farther. To the south, short stretches of a fairly large thrust fault can be found on several of the blocks between the high-angle faults that cut the belt, and east of Whitehall, New York (B3), a fault bringing Potsdam sandstone over Lower Ordovician dolomite appears (seen on side road to Stop 8) and can be traced continuously southward for some miles (seen between Stops 6 and 7). East of Fort Ann (C3), however, it runs out into the Snake Hill slate.

On the other hand, the Middle Ordovician rocks in this belt are commonly tightly folded and cut by numerous closely-spaced thrust faults, most of them too small to map. The shale or slate at the top of the section shows good cleavage in most exposures. South of Fort Ann, the structure in the Snake Hill shale or slate probably consists of tight folding and close imbrication, but poor exposures and the lack of traceable beds makes larger features undecipherable.

The structural position of the masses of Normanskill and older slaty rock in this belt (from Schuylerville (D2) south, cross-hatched on the map) is not understood. These rocks are of the same age as the Middle and Lower Ordovician carbonate rocks in the same belt at Fort Ann and northward and also in part at least as the carbonate rock in the fault slice east of Schuylerville at Bald Mountain (Stop 1), but their facies is that of the Taconic sequence to the east. If they are roughly in place, projecting up through the younger Snake Hill shale as anticlinoria or "upthrust" blocks, there has been an extraordinarily rapid facies change. If on the other hand they are exotic klippen "overthrust" from the Taconic belt to the east, the displacement must be very large, for on this theory they would have to come at least from east of the eastern carbonate sequence now exposed around Manchester (D4) and Bennington (E4), Vermont.

Belt of Taconic Slate

General. The Taconic Mountains and a wide belt of foothills to the west are composed chiefly of slate and phyllite. This mass of slate and phyllite forms a large complex synclinorium, and it was thought for years to lie conformably above the rocks of the western and eastern carbonate sequence on either side. As the top of each carbonate sequence is Middle Ordovician, this view required that the slate and phyllite be Middle Ordovician or higher. The discovery of numerous localities of Lower Ordovician and Lower Cambrian fossils in the slate mass showed, however,

that most of the sequence is in fact an argillaceous facies of parts of the two carbonate sequences. Opinion since then has been divided between the view that the slate is roughly in place and originally lay between two separate bodies of carbonate rock, being related to them either by unconformity or by rapid facies change (the view expressed by Dale, 1899, 1904a, 1904b, and Bain, 1938, and for areas farther south by Balk, Ruedemann, and Bucher), and the view that it originally lay many miles farther east and was brought to its present position as a great thrust sheet, now a vast klippe resting discordantly on the carbonate facies and folded with it into the existing synclinorium (the view expressed by Ruedemann, 1909, pp. 189-192; Keith, 1912, 1913, 1932; Cushing and Ruedemann, 1914, pp. 112-115; Prindle and Knopf, 1932; Kay, 1942, p. 1618; Cady, 1945; Kaiser, 1945; Fowler, 1950; and Bonham, ms.; and accepted by the present writers). Present opinion appears to favor the thrust-sheet theory for the northern part of the Taconic Mountains, the part included on the accompanying map, but to lean rather toward the inplace theory for the southern part, as in Dutchess County, New York. Whether such a combination of theories is logical or tenable remains to be determined.

The western boundary of the slate mass is fairly well defined, and it is accepted as a thrust fault even by most of those who doubt that the whole mass is a klippe. (It will be seen at Stops 1 and 8). The eastern boundary on the other hand is much less certain, for in most areas the argillaceous rocks of the Taconic sequence rest against Middle Ordovician argillaceous rocks which <u>are</u> conformable on the eastern carbonate sequence, and both have been metamorphosed to phyllite since the faulting if any. (This boundary will be seen at Stop 13). The route of the present trip lies close to the western boundary fault from Troy (F2) to Argyle (D3) and revisits it at Stop 8. From Stop 9 to Stop 13, the route crosses the Taconic belt.

<u>Stratigraphy</u>. Table 3 gives the units that have been described in reports on the Taconic slate belt (Dale, 1899, 1904a; Cushing and Ruedemann, 1914; Ruedemann, 1930; Prindle and Knopf, 1932; Larrabee, 1939; Kaiser, 1945; Fowler, 1950). It should be noted that the section as given is composite; not all the units have been recognized in any one area. Stops 9 to 13 display rocks supposed to belong to several of these formations.

The thicknesses and descriptions given in Table 3 are taken from the literature but most of the thicknesses are bare minima; the total thickness, especially of the Lower Cambrian units other than the Nassau, may well be several times greater. Rousseau H. Flower (personal communication) has suggested that the Nassau beds to the south are the facies equivalent of a large part of the Lower Cambrian section to the north. Similarly, the relations at Stops 9 to 11 suggest that the Mettawee and Schodack formations as hitherto mapped may be in part interfingering facies. The name Schodack formation has also been used in a broad sense to include all the Lower Cambrian units except the Nassau beds; in this usage the name Greenwich formation (Dale, 1904a, p. 50) has priority.

The base of this section is nowhere known to be exposed. The Bird Mountain grit in the north is intercalated in phyllite that may be metamorphosed Nassau; the Rensselaer grit in the south lies in contact with and above units of both the slate sequence and the eastern carbonate sequence. Dale (1893), Clarke (1909, p. 159), and Ruedemann (1930, pp. 127-130) believed that it rests unconformably upon them and is therefore younger (Silurian according to Dale, Devonian according to Clarke and Ruedemann); Prindle and Knopf (1932) believed that it is thrust over them and is Lower Cambrian or older.

Unless the Rensselaer grit is post-Middle Ordovician, no beds above the Normanskill formation are known in the Taconic belt proper, but to the west, from Schuylerville south, the Normanskill and the other Ordovician formations are associated with the younger Snake Hill shale within what appears to be the southern continuation of the western carbonate belt. The relations here are in doubt.

The correlation of the Ordovician units with the carbonate sequence is not certain. The Normanskill is pre-Snake Hill (middle Trenton) and has long been classified as Chazy, though Ruedemann (1901) first assigned it to the lower Trenton. The evidence of lower Trenton fossils in both pebbles and matrix of the intercalated Rysedorph Hill conglomerate should be decisive, though of course the Normanskill may extend down into the Black River. Likewise the Deepkill has been assigned entirely to the Beekmantown, but fossils in pebbles and limestone-conglomerate beds from the upper Deepkill are reported to be Chazy in age (Ross, ms.), so that it must extend at least that high. The Schaghticoke shale is lowermost Ordovician (Tremadoc).

In the eastern part of the Taconic belt, in the Taconic Mountains proper, the grade of metamorphism rises from slate to phyllite, no fossils are found, and the rocks cannot be divided into Cambrian and Ordovician portions. Moreover, as noted above, it is commonly difficult to distinguish the Taconic phyllite from the phyllite at the top of the eastern carbonate sequence. On the accompanying map all these rocks are mapped together as undifferentiated phyllites.

Igneous rocks are known locally in the Taconic belt. A number of diabase, camptonite, and other lamprophyric dikes have been found in the north part of the belt and also in adjacent parts of the belts west and east; these have not been shown on the map. Masses of basalt that may be remnants of flows are known in several places within the Rensselaer grit.

Structure. The structure of the Taconic slate mass is complex and poorly known. Certainly virtually all of it shows small-scale folds overturned to the west and strong cleavage mostly dipping east; much of it shows a later slip cleavage crossing an earlier slaty cleavage. Larger features come out only by regional mapping of the difficultly distinguishable units; these seem to outline larger generally tight compound folds. At the northern end of the belt, however, where the most detailed published maps are available (Larrabee, 1939; Kaiser, 1945; Fowler, 1950), the folding appears to be shallow, and the layers, though tightly crumpled, extend nearly horizontally. Curiously, faults, especially thrust faults, have rarely been recognized within the mass, even or especially where the most detailed work has been done. As noted above, some feel that the Rensselaer grit is a separate thrust sheet above the main mass of slate.

Similarly the mass as a whole is fairly certainly bounded on the west by a major thrust fault, exposed or nearly exposed at several localities (Poesten Kill gorge at Troy, Stop 1, Stop 8), and most geologists familiar with the north part of the Taconic belt now incline to believe that this fault underlies the entire mass, at least within the area shown on the accompanying map, reappearing along the eastern border (Stop 13). The evidence there, however, is far from satisfactory, as the rocks have evidently been metamorphosed since any faulting.

If the Taconic slate mass is a klippe, then it ought to have roots somewhere in the belts to the east. This question is discussed below in the description of southern Vermont. The lateral movement of the klippe can hardly have been less than 25 miles on the most favorable assumptions and may have been much more. It is possible, however, that not all this movement is genuine thrusting in response to tangential force; perhaps part of it is "écoulement", gravity gliding of the

detached klippe down the west slope of the rising Green Mountain anticlinorium into its present position.

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SOUTHERN VERMONT

By James B. Thompson, Jr.

General Statement

The Green Mountains in southern Vermont coincide with the axis of a major anticlinorium. In the core of the anticlinorium is a crystalline complex of pre-Cambrian age. On the western limb of the Green Mountain anticlinorium, which may also be regarded as the eastern limb of the Middlebury synclinorium (Cady, 1945), the basement rocks are overlain with profound unconformity by sedimentary rocks of Cambrian to Middle Ordovician age. The oldest dated rocks in this younger sedimentary series are lowest Cambrian, demonstrating beyond all doubt the pre-Cambrian age of the Green Mountain basement complex.

On the east the Green Mountain basement complex is overlain, again with profound angular unconformity, by a thick series of metasedimentary and metavolcanic rocks. The upper part of this series is sparsely fossiliferous and includes rocks of middle Ordovician age and some possibly younger. The lower part of the series is non-fossiliferous but is believed to be largely of Cambrian or early Ordovician age.

Resting with structural discordance upon the younger rocks of the Middlebury synclinorium, and forming the greater part of the Taconic mountains is a third sedimentary series, also of Cambrian and Ordovician age.

These three sedimentary series will be referred to respectively as the Vermont Valley sequence, the Eastern Vermont sequence, and the Taconic sequence. Although presumably equivalent in age, they differ markedly in lithologic facies. The Vermont Valley sequence is largely carbonate rock with minor sandstone and shale or their metamorphosed equivalents; the Eastern Vermont sequence is largely metamorphosed shale and sandstone with interstratified volcanics; and the Taconic sequence is largely sandy and shaly with minor carbonates and volcanics. The Taconic sequence thus appears, lithologically, to occupy an intermediate position between the other two.

The dominant structural feature east of the Green Mountain anticlinorium is a series of complex, domical anticlines just west of the Connecticut river. The largest of these, the Chester dome, is crossed by both the line of the cross-section (Plate 4) and the route of the excursion.

The youngest rock of the Eastern Vermont sequence occurs in the complexly folded and faulted belt along the valley of the Connecticut River.

All of the sedimentary and volcanic rocks in southern Vermont have been metamorphosed to some degree. The lowest grade rocks (chlorite zone) are in the western Taconics, on the western limb of the Middlebury synclinorium, and in a narrow belt along, or immediately west of the Connecticut River. The highest grade rocks (staurolite zone) are associated with the series of domes west of the Connecticut River.

The map of southern Vermont (Plate 4) is based mainly upon recent field work, much of which is still in progress, and very little of which has been published. Inasmuch as the field work is still actively under way, it must be made clear that many of the interpretations given here or incorporated in Plate 4 must be considered tentative and may quite possibly be altered, perhaps drastically, within the next few years.

Green Mountains

Lithology. The pre-Cambrian rocks in the core of the Green Mountain anticlinorium are relatively little known inasmuch as most mapping in that region to date has been carried out with the principal aim of separating the pre-Cambrian from the Paleozoic. A great variety of lithologic types, however, is known to be present, including gneisses, schists, quartzites, amphibolites, coarsely crystalline marbles and calc-silicate rocks, all intensely deformed, metamorphosed and intruded by mafic dikes, pegmatites and coarsely porphyritic granite (Stamford granite), before the deposition of the Paleozoic formations. The metasedimentary rocks were named the Mount Holly series by Whittle (1894) but no stratigraphic sequence has been established.

Structure. In the central part of the pre-Cambrian area the structural trends average about east-west in marked discordance to the Paleozoic structures. Near the borders of the massif, however, the pre-Cambrian structures have been rotated in some areas into pseudo-conformity with those of the Paleozoic rocks although elsewhere a ninety-degree discordance has been observed.

Vermont Valley

Stratigraphy. The formations of the Vermont Valley sequence (Table 4) crop out in a narrow, north-south belt between the pre-Cambrian rocks of the Green Mountain basement complex on the east and the rocks of the Taconic Mountains on the west. North of the end of the Taconic Mountains in the Brandon quadrangle the Vermont Valley formations are continuous along the axis of the Middlebury synclinorium with the rocks described in an earlier part of this guidebook as the western belt of deformed carbonate rocks, the Vermont Valley sequence thus forming the eastern belt of deformed carbonate rocks. At the south end of the Green Mountains near North Adams, Massachusetts, the Vermont Valley sequence is in contact with the eastern Vermont sequence. The nature of this contact is uncertain but has been shown as a fault on Plate 4, following Prindle and Knopf (1932).

The Vermont Valley sequence ranges in age from lowest Cambrian to Middle Ordovician. The basal units are chiefly quartzite, phyllite, greywacke, and conglomerate. The central and largest portion is largely carbonate with dolomitic limestones dominant in the older formations and calcitic limestones in the younger. The extreme upper part is slate and phyllite. In the northern areas of the Vermont Valley sequence the lowermost formations, the Mendon series of Whittle (1894), have formerly been assigned to the late pre-Cambrian on the basis of their non-fossiliferous nature and a supposed unconformity between them and the Cheshire quartzite in the eastern part of the Brandon quadrangle. Recent work has shown, however, that this unconformity, if real, is not a major one, and that the Mendon series is actually equivalent to rocks mapped as part of the Cheshire quartzite farther south. The quartzite north of Williamstown, Massachusetts, where Walcott (1888) found trilobite fragments suggesting a lower Cambrian age, is apparently equivalent to the uppermost part of the Pinnacle arkose, the basal formation of the Mendon series.

Recent mapping, however, has shown the existence of a marked angular unconformity within the carbonate rocks of the Vermont Valley sequence, at the base of the Whipple marble. Fowler (1950) shows the Whipple as resting unconformably on all older formations down to and including the Winooski dolomite. Farther south the writer has found the Whipple truncating the entire lower part of the Vermont Valley sequence over a distance of but a few miles and coming into direct contact with the pre-Cambrian basement. This appears to indicate a major orogenic movement in early Ordovician time, perhaps to be correlated with the unconformity described by Bucher (1951) in southeastern New York, or the Mine Ridge disturbance in eastern Pennsylvania.

Exact dating of the unconformity is unfortunately not possible at present. Cady (1945) and Fowler (1950) correlated the Whipple with the Glens Falls limestone and placed the unconformity within the Middle Ordovician. The presence, however, of rocks in the lower part of the Whipple lithologically similar to the Orwell and Middlebury limestones suggest that the Whipple may be in part older than the Glens Falls, and that the disturbance may have taken place between Lower and Middle Ordovician time.

The thicknesses of the formations in Table 4 are based largely on mapping by the writer in the vicinity of Wallingford except where otherwise noted. Cady (1945) and Fowler (1950) give considerably greater thicknesses for the areas immediately to the north, suggesting that the formations of the Vermont Valley sequence thin southward.

Structure. The Vermont Valley sequence may be regarded either as occupying the eastern limb of the Middlebury synclinorium or the western limb of the Green Mountain anticlinorium. The subsidiary folds are commonly overturned to the west and locally, as west of Rutland and northwest of Bennington, pass into overthrusts. The axial planes of the minor folds dip from twenty to forty-five degrees easterly, the dip of the axial planes steepening, in general, toward the east.

Taconic Mountains

Stratigraphy. The rocks of the Taconic Mountains in southern Vermont are largely green phyllites grading westward into green and purple slates. Associated with the green phyllites are lesser amounts of black and gray phyllite and a few areas of quartzite and coarse grit. Most of these have been shown on Plate 4 as undifferentiated phyllites except at the northern end of the range.

Although shown in some intricacy on Plate 4, the eastern border of the klippe is not located with any great degree of certainty. In the Castleton quadrangle Fowler (1950) placed the eastern limit of the klippe at the contact between black phyllites believed to be autochthonous and of Middle Ordovician age, and non-fossiliferous green phyllites and grits, believed to be of Cambrian age by correlation to the west. This contact has been traced about halfway through the Pawlet quadrangle by the writer and is apparently the boundary used by Prindle and Knopf (1932) to delimit the klippe farther south. In the Equinox quadrangle and the southern half of the Pawlet quadrangle, the eastern edge of the klippe is shown as following the schist-limestone boundary of T. N. Dale (1912). This is not consistent with the mapping to the north and south inasmuch as there is present, at all points observed by the writer, a zone several hundred feet thick of black phyllite between the Ordovician limestones and the green phyllites forming the main mass of the Taconics. Unfortunately Dale did not differentiate the phyllites and the writer's reconnaissance is insufficient to do so. The black phyllite zone is so narrow where observed in this area, however, that the difference would probably not show upon Plate 4. Prindle and Knopf (1932) also noted that in parts of the Greylock quadrangle the black phyllite zone was too narrow to map separately.

The validity of the contact between the green and black phyllites as marking the eastern edge of the Taconic klippe is, of course, open to question. Where exposed (Stop 13) there is no discordance or other direct evidence of faulting. Although the lower part of the black phyllite is conformable upon fossiliferous Middle Ordovician limestones and apparently interbedded with them, this does not preclude the possibility that some of the black phyllites may be allochthonous. It is also possible that all or part of the green phyllites may be in place. The correlation of the green phyllites and grits of the eastern Taconics with the fossiliferous Cambrian in the western Taconics is somewhat uncertain owing to the lack of detailed mapping in the intervening areas.

Structure. The phyllites of the Taconic Mountains appear in general to be crumpled into close folds of small amplitude and wave length overturned to the west. On most minor anticlines the western limbs are overturned with easterly dips as low as sixty degrees not uncommon. An axial plane slip cleavage is well developed in the phyllites of the eastern Taconics. The slip cleavage strikes approximately north-south and dips from twenty to forty degrees east. Westward this slip cleavage appears to pass with decrease in metamorphism into typical slaty cleavage.

There does not seem to be any significant difference between the minor deformation in the Taconic phyllites and in those mapped as part of the autochthonous sequence, the supposed fault plane itself apparently being folded in the same manner (Stop 13). This, combined with the fact that there is no break in the metamorphism, suggests that the Taconic thrusting, if any, occurred early in the tectonic history of the area.

Southeastern Vermont

Stratigraphy. The rocks overlying the Green Mountain basement complex on the east (Table 5) are mainly mica schists and quartzites interstratified with greenstone schists, amphibolites and gneisses. The mica schists and quartzites are metamorphosed shales and sandstones, and the greenstone schists, amphibolites and gneisses are largely metamorphosed volcanics.

The thicknesses in Table 5 apply to the eastern limb of the Green Mountain anticlinorium in the vicinity of Ludlow. The figures refer to present apparent thickness

(White and Jahns, 1950, p. 190) without correction either for tectonic thinning as indicated by the deformation of conglomerates (Stop 2, second day), or for duplication by minor folding. It is possible that these effects counteract each other to some extent, but the risk in estimating original stratigraphic thickness in a metamorphosed terrane cannot be overemphasized. Apparent thicknesses are less south of Ludlow, and White and Jahns give values several times as great as those at Ludlow for the areas to the north. It is uncertain whether these differences are stratigraphic, structural or interpretative, although there seems to be a parallel southward thinning of the Vermont Valley sequence west of the Green Mountains. The extreme thinness of the formations about the Chester dome, however, is believed by the writer to be of tectonic origin.

Identifiable fossils have been found only in the upper part of the eastern Vermont sequence and most of those found have not been suitable for precise dating. The well-known graptolite locality at Magog, Quebec is considered by Currier and Jahns (1941) to be in slate equivalent to the upper part of the Cram Hill formation of Vermont. If so, this would indicate a Middle Ordovician (late Normanskill) age for that formation. The formations older than the Cram Hill have not yet yielded any fossils and are thus Middle Ordovician or older. The lack of any marked stratigraphic break at the base of the Cram Hill suggests that there is no major hiatus between it and the older formations. The interpretation most generally accepted at the present time is that the Cram Hill and older formations are equivalent in age to the autochthonous Cambro-Ordovician sequence west of the Green Mountains. In support of this interpretation is the fact that the quartzites and dolomites in the Hoosac formation in the area about Plymouth and Ludlow, Vermont are lithologically similar to parts of the Lower Cambrian sequence west of the Green Mountains. This interpretation, if valid, implies a rapid facies change from the Cambro-Ordovician carbonate sequence west of the Green Mountains to the shale-sandstone sequence with intercalated volcanics on the east.

An alternative interpretation with much to commend it is that the pre-Cram Hill formations are all of Middle Ordovician age and to be correlated only with the rocks above the mid-Ordovician unconformity west of the mountains. A critical area in this regard is the region between North Adams, Massachusetts and Heartwellville, Vermont, where the Cambro-Ordovician formations of the western sequence are in contact with the Hoosac formation and apparently truncated by it. Prindle and Knopf show this contact as a fault. If so, the ages are indeterminate. If an unconformity, the alternative interpretation given above would be correct.

The formations younger than the Cram Hill are richer in paleontologic evidence but most of it, unfortunately, is inconclusive. Crinoid fragments found by Currier and Jahns (1941) in the Shaw Mountain formation indicate, by their size, a Middle Ordovician or younger age. Graptolites collected from the Northfield formation by Richardson (1919) and identified by R. Ruedemann as probably Normanskill were discredited by Foyles (1931). Corals found by Cady (1950) in the Waits River formation suggest a Middle Ordovician age, and a possible brachiopod found by Doll (1943) in the upper part of the Gile Mountain formation is interpreted by him as indicating a Devonian or Silurian age. White and Jahns (1950), however, do not accept Doll's interpretation.

In the spring of 1950 fossils were found by the writer and Mr. Arthur Boucot on Skitchewaug Mountain near Springfield, Vermont, in quartzites mapped on Plate 4 as part of the Orfordville formation. The fossils include crinoid fragments, brachiopods and corals, unfortunately too badly deformed to indicate more than a late Ordovician or younger age. Although the mapping of the Skitchewaug Mountain rocks as part of the Orfordville formation may be in error, owing to the structural

complexity of the area, it is certain nevertheless that they are younger than any other part of the eastern Vermont sequence. The Skitchewaug Mountain rocks, it might be pointed out, bear a lithologic resemblance to the rocks in the vicinity of the fossiliferous limestone at Bernardston, Massachusetts, considered by Balk (1941) to be of Devonian age. Re-examination of the Bernardston fossils, however, by Boucot (personal communication) suggests that a Silurian age is more probable.

The origin and age of the gneisses in the cores of the Chester (C-6, D-6) and Sadawga (E-5) domes is highly problematical. In stratigraphic position they are beneath rocks correlated with the Tyson formation on the eastern limb of the Green Mountain anticlinorium. There is, however, no evidence of angular unconformity or other sharp break at the contact, nor does the gneiss in the domes show the heterogeneity of the Green Mountain basement complex. The rocks in the cores of the domes are largely banded gneisses of granodioritic or quartz dioritic composition with minor amounts of biotite-amphibolite and a few lenses of schist and quartzite. Compositionally the gneisses could be metamorphosed felsic volcanics, perhaps mixed with greywacke or arkose, but few primary features are preserved other than a pronounced banding, best developed about the margins of the dome. There seem to be several possibilities: the gneiss in the domes could be interpreted as a part of the Green Mountain basement complex with the unconformable relations obliterated by extreme deformation (Balk, 1936, p. 732); as a tremendous thickening, eastward, of the basal clastics of the Tyson formation with admixed volcanic material; or as a separate series, older than the Tyson formation, and not present in the Green Mountain area. It might be suggested that the gneisses were formed by the metasomatic transformation of some other pre-existing rock, but there is no clear-cut evidence of regional metasomatism in the overlying rocks.

<u>Plutonic rocks</u>. Igneous rocks ranging in composition from serpentinized dunite to granite are intrusive into the metasediments and metavolcanics of southeastern Vermont. Small metamorphosed dikes, both felsic and mafic, are common in many areas and are believed to be related to the vulcanism accompanying sedimentation.

A series of ultramafic intrusives most of them too small to be shown on Plate 4, crops out in a north-south belt just east of the Green Mountain axis and also in the Chester dome. These are apparently the oldest of the plutonic rocks, antedating the metamorphism and most, if not all, of the deformation. It is possible, in fact, that the ultramafics were emplaced during the sedimentation inasmuch as none are found in rocks younger than the Cram Hill formation.

Several bodies of two-mica granite, quartz monzonite and granodiorite are clearly younger than any of the metasedimentary rocks and apparently syntectonic. These are similar to the well-known Barre "granite" farther north, and to the granitic rocks of the New Hampshire magma series (Billings, 1934).

The alkalic stocks at Cuttingsville (C-5) and Mount Ascutney (C-6,7) are clearly younger than both the deformation and the regional metamorphism. These are largely syenite with minor amounts of gabbro, diorite, granite and volcanic rock. The rocks are similar in all respects to those of the White Mountain magma series of New Hampshire (Billings, 1934) and are so correlated. At both Cuttingsville and Ascutney there are numerous dikes of both trap and felsite with a rough radial arrangement about the central stock.

It is probable that some of the fresh diabase dikes in the valley of the Connecticut River, however, are of Triassic age. If so, these are the youngest rocks in the area.

Structure. The major structural features in southeastern Vermont are the eastern limb of the Green Mountain anticlinorium and the belt of domes just west of the Connecticut River.

The rocks on the eastern limb of the Green Mountain anticlinorium dip forty to forty-five degrees east at the contact with the pre-Cambrian, steepening eastward to vertical at the axis of the syncline separating the Green Mountain anticlinorium from the domes. The minor folds are normal for the eastern limb of an anticline except for a fanning of the axial planes. In the Ludlow area the axial planes dip about fifty degrees east at the pre-Cambrian contact, steepen to vertical about two miles to the east, and acquire increasingly gentle westward dips farther east toward the Chester dome. In Plymouth and Ludlow the contact with the pre-Cambrian has been offset by high angle reverse faults (Plate 4) dipping about fifty degrees east.

The domes east of the Green Mountains are probably the most unconventional structures in the entire area. From north to south these are the Strafford dome (A-7), the Pomfret dome (B-7), the Chester dome (C-6,7, D-6), the Ray Pond dome (E-5), the Sadawga dome (E-5) and the Guilford dome (E-6). Similar features in western Massachusetts have been described by Balk (1946).

Among the structural features peculiar to the domes are a marked thinning of the mantling formations and the abnormal "Christmas-tree" pattern of the subsidiary folds. The thinning of the surrounding rocks is perhaps most marked about the Chester dome where the various units are about one-tenth as thick as the same units on the eastern limb of the Green Mountain anticlinorium a few miles to the west. That this thinning is at least in part tectonic is suggested by the abundance of boudinage and the extreme flattening of amygdules and conglomerate pebbles.

The nature of the subsidiary folds is largely responsible for the peculiar map-pattern of the domes. The sense of these folds is precisely the reverse of that on a conventional anticline, the axial planes and related slip cleavage forming a flat arch. The nature of the folds, suggesting the flowage-folding of Bain (1931), and the thinning of the formations would be consistent with a relative upward movement of the central mass. White and Jahns (1950) have interpreted certain features of the Strafford dome as an arching of the axial planes of pre-existing folds. The writer is of the opinion, however, that all of the folding can be related to the doming.

Major Problems in Southern Vermont

Roots of Taconic fault. The problem of locating the eastern limit of the Taconic klippe has already been mentioned. Related problems are the source of the klippe and its mode of emplacement. Keith (1932) placed the root of the fault at a line corresponding to the present base of the Pinney Hollow formation. Hawkes (1941), however, showed this to be a gradational sedimentary contact, a conclusion with which the writer and other later workers concur. This leaves several possibilities. One is that the faulting may have been essentially a gravity-sliding from the crest of the rising Green Mountain anticlinorium with the root zone since removed by erosion. Another is that the fault passes into a "distributed thrust" on the eastern limb of the anticlinorium with no single, distinct plane of movement. A third possibility is that the root is in the pre-Cambrian core of the Green Mountains, as yet undetected and possibly continuous with the fault shown by Prindle and Knopf (1932) just east of North Adams, Massachusetts. Mapping in the northern part of the pre-Cambrian area, however, has failed to show the existence of such a fault. The possibility that the Taconic root may lie in one of the faults near the

Connecticut River seems to be ruled out by the fact that the Taconic sequence appears to represent a sedimentary facies intermediate between the carbonates beneath it and the eastern Vermont sequence.

Origin of the gneiss domes. In addition to the problem of the origin of the core-gneisses there is that of the origin of the domal structures themselves. One hypothesis is that the domes are anticlines formed by the conventional lateral compression and complicated by flowage on the flanks. Another is that the domes were formed entirely by vertical movements, perhaps, as in the case of salt domes, related to slight density differences in highly plastic rocks.

Relations of the eastern Vermont sequence to the rocks of western New Hampshire. One of the matters of least certainty on Plate 4 is the nature of the contact between the Gile Mountain and Orfordville formations. On Plate 4 it will be noted that the Gile Mountain is gradually cut out, southward, by the Orfordville. On some previous maps (Hadley, 1950) this has been shown as a fault contact but there is little or no positive evidence of such faulting in southern Vermont. The Hardy Hill conglomerate in the lower part of the Orfordville may indicate an unconformity, but it is also possible that the differences between the two formations may be no more than a lateral variation in rocks of the same age. Particularly critical with regard to this problem are the age and structural relations of the fossiliferous rocks at Springfield, Vermont, and Bernardston, Massachusetts.

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SOUTHERN NEW HAMPSHIRE

By Marland P. Billings

Stratigraphy and Metamorphism

Northwest of the body of "granite, quartz monzonite and granodiorite" on Plate 4, the metamorphosed sedimentary and volcanic rocks of New Hampshire have been assigned to formations of Ordovician (?), Silurian and Devonian age. The Ordovician (?) rocks have been assigned to the Standing Pond, Gile Mountain, Orfordville, Albee, Ammonoosuc and Partridge formations. The Silurian rocks belong to the Clough and Fitch formations. The Devonian rocks have been assigned to the Littleton formation. The Moat volcanics of Mississippian (?) age are confined to the northeastern corner of the map but have not been separately distinguished from the plutonic members of the White Mountain magma series on Plate 4.

The metamorphosed sedimentary and volcanic rocks in the southeastern part of the State — that is the rocks southeast of the body labelled "granite, quartz monzonite, and granodiorite" — are considered to be Paleozoic, probably Silurian and perhaps including some Ordovician. North of latitude 43°00' N. these rocks have been divided into the Rye, Kittery, Eliot, and Berwick formations. South of latitude 43°00' N. the Kittery, Eliot and Berwick formations have not been separately mapped and are collectively assigned to the Merrimack group.

All of the original sedimentary and volcanic rocks of southern New Hampshire, with the exception of the Moat volcanics, have been regionally metamorphosed. The grade of metamorphism differs greatly throughout the area. A belt of low-grade metamorphism follows the Connecticut River. Toward the southeast the metamorphism increases; throughout a central belt that trends northeast and is forty miles wide the metamorphism is high-grade. In the southeast part of the state the metamorphism is low-grade to middle-grade, but around Portsmouth it again attains a high-grade.

The stratigraphic sequence and lithology of the various formations in southern New Hampshire is shown in Table 7. These descriptions are regrettably complex for some formations, because of the presence of stratigraphic members as well as differences in grade of metamorphism.

The age of the rocks given in Table 7 is based on comparatively few fossil localities. Lower Devonian fossils have been found in the Littleton formation near Littleton, New Hampshire (beyond the limits of Plate 4). Another fossil locality at Bernardston, Massachusetts (F6), just west of the Connecticut River and south of the Vermont border, is important. Fifteen years of mapping in western New Hampshire shows that the Littleton formation can be correlated with the Bernardston formation, which Schuchert (Schuchert and Longwell, 1932) considered Lower Devonian. Middle Silurian fossils have been found in the Fitch formation in the Littleton district. The Clough formation, transitional upward into the Fitch formation, is considered Lower or Middle Silurian. The Partridge and older formations are unconformable beneath the Silurian formations. Present evidence indicates that they overlie the Waits River formation which recent paleontological data indicates to be Middle Ordovician. The Standing Pond, Gile Mountain and Orfordville formations are tentatively called Middle Ordovician (?) whereas the Albee, Ammonoosuc, and Partridge formations are called Upper Ordovician (?).

The metasedimentary rocks of southeastern New Hampshire are of uncertain age. Evidence in Massachusetts (R. H. Jahns, personal communications) indicates that the Merrimack group is unconformable beneath schists that are believed to be the more highly metamorphosed phase of the Pennsylvanian Worcester phyllite. Hence the Merrimack group is Pennsylvanian or older. Freedman, on the basis of a very tenuous correlation with the Middle Silurian Waterville slates of central Maine, believes the Merrimack group may be Silurian. The Rye formation may be Upper Ordovician.

Plutonic Rocks

The plutonic rocks of western and central New Hampshire have been assigned to four magma series by Billings (1934) (Table 8).

The Highlandcroft magma series, confined to the northwestern corner of that part of New Hampshire in Plate 4, is unconformable beneath the Silurian and inasmuch as it intrudes rocks of presumed Upper Ordovician age, it is considered to be Late Ordovician (?). The only member of this series exposed within the limits of Plate 4 is a medium-grained to coarse-grained greenish gray or pink biotite-quartz monzonite. Elsewhere in New Hampshire this series contains hornblende granodiorite, quartz diorite, and diorite.

The Oliverian magma series is mostly confined to the cores of a series of domes that extend northward from the southwest corner of New Hampshire to the north edge of Plate 4. The most characteristic rocks are pink to gray granulated medium-grained to coarse-grained granitic rocks that are foliated to massive. The principal dark mineral is biotite, although locally some hornblende is present. Depending upon the ratio of potash feldspar to total feldspar the most common rocks are granodiorite

and quartz monzonite, but granite and quartz diorite are present. The Lebanon granite is tentatively assigned to the Oliverian magma series.

The New Hampshire magma series within the limits of Plate 4 in western and central New Hampshire consists of: (1) amphibolite dikes and sills; (2) Bethlehem gneiss; (3) Kinsman quartz monzonite; (4) quartz diorite (Winnipesaukee and Spaulding); and (5) binary granite (Concord). The principal dark mineral in all these rocks is biotite, except in the amphibolites, in which, of course, it is hornblende.

The plutonic rocks mapped in southeastern New Hampshire as (1) diorite (including the Exeter diorite), (2) Ayer granodiorite, (3) granite, quartz monzonite, and granodiorite, and (4) binary granite are tentatively assigned to the New Hampshire series.

The scores of separate units within the White Mountain magma series are not distinguished on Plate 4. Some of the magma of this series erupted on the surface of the earth as the Moat volcanics — flows, tuffs, and breccias, with the composition of basalt, andesite, trachyte and rhyolite. However, much of the magma consolidated beneath the surface to form stocks and ring-dikes of gabbro, diorite, monzonite, syenite, nephelite-sodalite syenite, quartz syenite, amphibole granite, and biotite granite.

In the extreme southeastern corner of the State there is a small area of Newburyport quartz diorite. In Massachusetts this rock is considered to be comagmatic with the Salem-Dedham magma series. Billings and Dowse believe that this series is pre-Cambrian. It is possible, however, that the Newburyport quartz diorite does not belong to the Salem-Dedham series and it may be one of the members of the New Hampshire magma series.

The determination of the age of the Oliverian, New Hampshire and White Mountain magma series is based on the following arguments:

(1) All these rocks are believed to be younger than the Lower Devonian Littleton formation. There is ample field evidence that the rocks of the New Hampshire and White Mountain magma series cut the Littleton formation. Moreover, in the Mascoma quadrangle the Silurian Clough quartzite is feldspathized where it is in contact with the Oliverian magma series. Since the unconformity between the Silurian and Devonian in New Hampshire is not pronounced, it is believed that the Oliverian must also be younger than the Littleton formation.

(2) The Moat volcanics may be correlated with the alkaline volcanics in the Blue Hills south of Boston, Massachusetts. These volcanics in the Blue Hills are unconformable beneath the fossiliferous Pennsylvanian rocks in the Norfolk Basin. Hence the Moat volcanics as well as the plutonic phases of the White Mountain magma series are considerably younger than the Lower Devonian but are pre-Pennsylvanian. They are tentatively considered to be Mississippian (?).

(3) The following sequence of events took place from the Lower Devonian to the Mississippian (?):

(a) Deposition of the Littleton formation
(b) Emplacement of the Oliverian magma series
(c) Intrusion of the mafic forerunners of the New Hampshire magma series, now amphibolite dikes and sills
(d) Regional metamorphism, in part contemporaneous with the emplacement of the New Hampshire magma series
(e) Deep erosion
(f) Eruption of the Moat volcanics.

The Oliverian magma series is hence tentatively assigned to the Middle Devonian (?) and the New Hampshire magma series to the Late Devonian (?).

In Massachusetts, plutonic rocks that are continuous with rocks in New Hampshire that have been assigned to the Oliverian and New Hampshire magma series are considered to be Late Carboniferous. If this were true the Oliverian and New Hampshire magma series would be in whole or in part Late Carboniferous. The White Mountain magma series would then be Permian (?). However, evidence obtained from Massachusetts is very unsatisfactory. The reported Pennsylvanian fossils from the Worcester phyllite have been lost.

Structure

General statement. A brief inspection of Plate 4 shows that the tectonic belts in southern New Hampshire trend northeasterly. More precisely, in the western part of the State the tectonic trends are approximately N. 10° E., whereas in the southwest corner of the State the tectonic trend is more nearly N. 50° E. Numerous bodies of plutonic rocks complicate the structure displayed by the metamorphosed sedimentary and volcanic rocks.

The following structural belts are present in southern New Hampshire: (1) the Connecticut Valley belt of folds and thrusts; (2) the Bronson Hill anticline, characterized by a series of en echelon domes in which the Oliverian magma series is exposed; (3) the central synclinorium; (4) the Fitchburg pluton (rocks mapped as "granite, quartz monzonite, and granodiorite"); (5) Rockingham anticlinorium.

Connecticut Valley belt of folds and thrusts. A major fault, the Northey Hill thrust, separates this belt from the Bronson Hill anticline to the east. This fault enters the north edge of Plate 4 five miles east of the Connecticut River. For sixty miles to the south the fault lies east of the river. But three miles north of Bellows Falls it crosses to the west side of the river and some 35 miles further south it enters Massachusetts about five miles west of the Connecticut River. The type locality for this fault is in the Moosilauke quadrangle, fifteen miles northeast of the northern border of Plate 4. Convincing stratigraphic evidence of the fault is found in the northern part of Plate 4, where the lower part of the Orfordville formation is in juxtaposition to beds several thousand feet up in the Littleton formation. The Albee, Ammonoosuc, Partridge, Clough and Fitch formations are missing. A fault of large magnitude must be present and Hadley (1942) estimates that the stratigraphic throw here is 13,000 feet. This fault has been very difficult to trace southward through Plate 4. Slates or schists of the Orfordville formation west of the fault are lithologically very similar to the slates or schists of the Littleton formation east of the fault. This fault is considered older than the regional metamorphism, because there is no difference in the grade of metamorphism on opposite sides of the fault.

The second large fault, the Ammonoosuc thrust, enters the northern border of Plate 4 one mile east of the Connecticut River. It can be followed southwesterly, very close to the Connecticut River, for forty-five miles. It apparently dies out in the vicinity of Claremont (C7). This fault, for which there is ample stratigraphic and structural evidence, dips, on the average, 38° NW. Local silicified zones are present. This fault is younger than the regional metamorphism, because in the northern part of Plate 4 and further north rocks in the chlorite zone west of the fault are in contact with rocks in the staurolite zone east of the fault.

Northwest of the Northey Hill thrust several folds are shown by the distribution of the formations on Plate 4. At the north end of the map the axis of a syncline lies less than a mile west of the Northey Hill thrust, where the Albee formation extends southward. Further south this syncline, marked by the belt of Post Pond volcanics, may be followed west of the Lebanon granite. Twenty miles further south it passes

east of the area of Standing Pond volcanics that lies east of the Connecticut River. The syncline is shown still further south by the pattern of the Hardy Hill quartzite, which plunges north and south from an axis culmination. The area of Standing Pond volcanics is in the core of a northerly plunge anticline.

The map-pattern of the formations around the Lebanon granite suggests a doubly plunging anticline, with granite in the core. However, although the folds and lineation on the northeast nose plunge northeasterly, those on the southwestern nose also plunge northeasterly. Thus the plunge of the southwestern nose of the Lebanon anticline is inverted, probably because of a second deformation after the first fold formed. Gravity observations by Bean (1951) also confirm the geological evidence that the granite is essentially an elliptical cylinder that plunges northeasterly.

East of the Lebanon anticline a synclinal axis lies between the two belts of Hardy Hill quartzite. This fold continues a few miles toward the southwest where it apparently merges with the syncline that passes west of the Lebanon anticline. The folds shown by the map-pattern of the Hardy Hill quartzite plunge northeasterly, presumably because of the same second deformation that affected the Lebanon anticline.

From a point four miles southeast of the Lebanon granite an anticline extends south-southwestward for twenty miles. The core of this anticline is occupied by phyllites of the Orfordville formation, on both flanks of which the volcanics of the Post Pond member appear. Eight miles south of the Lebanon granite an elliptical area of Hardy Hill quartzite indicates the crest of the anticline. East of this anticline is a long narrow syncline occupied by Post Pond volcanics.

<u>Bronson Hill anticline</u>. The Bronson Hill anticline is one of the major structural features of New Hampshire. The crest of this complex anticline, marked by the areas occupied by the plutonic rocks of the Oliverian magma series, lies five to ten miles east of the Connecticut River. The western limit of this anticline is the Northey Hill thrust. The eastern border is the eastern margin of the Bethlehem gneiss; south of the southern end of the Bethlehem gneiss the eastern margin of the Bronson Hill anticline may be arbitrarily placed three to four miles east of the eastern margin of the plutonic rocks of the Oliverian magma series.

The crest of the Bronson Hill anticline is marked by a series of domes. These domes show a core of the Oliverian magma series surrounded successively outward by elliptical belts of the Ammonoosuc and Clough formations, as well as the Fitch and Partridge formations where present. From north to south these domes are: (1) Owls Head dome (A9); (2) Smarts Mountain dome (A8; narrow dome cut off by an east-west fault at its south end); (3) Mascoma dome (B8); (4) Croydon dome (C8); (5) Unity dome (C7); and (6) Alstead dome (D7). In the southwest corner of the state the pattern is somewhat more complex. A large body of Kinsman quartz monzonite occupies a basin in the midst of several domes. The (7) Westmoreland-Swanzey dome lies north and east of the Kinsman (E7); the (8) Vernon dome lies to the west (E6); and (9) the north end of the Warwick dome lies to the south (F7). Whereas some of these domes are symmetrical, others, notably the Smarts Mountain and the Vernon domes, are overturned toward the west.

The Mt. Clough pluton, a large concordant body of Bethlehem gneiss, occupies most of the eastern limb of the Bronson Hill anticline in the northern two-thirds of Plate 4. Ten miles southeast of the Lebanon granite a basin of Bethlehem gneiss lies west of the south end of the Mascoma dome. Despite the presence of a large normal fault, this body of Bethlehem gneiss is obviously part of the main Mt. Clough pluton. In the northern part of Plate 4, the large body of Bethlehem gneiss west of the Oliverian magma series is presumably part of the main Mt. Clough pluton, now

detached by erosion.

A number of large normal faults, trending north-northeast, cut the Bronson Hill anticline. In the southwest corner of the state the large normal fault bounding the Kinsman quartz monzonite on the southeast is the northward continuation of the fault that bounds the Triassic rocks of northern Massachusetts on the east. Thus this fault, as well as the other normal faults to the north, are Triassic.

In three graben, ten to fifteen miles north of the Massachusetts border, the Ammonoosuc, Partridge, Clough, and Littleton formations have been dropped down into the Oliverian magma series.

Central synclinorium. East of the Bronson Hill anticline is a large area of high-grade schists belonging to the Littleton formation, into which numerous bodies of plutonic rocks belonging to the New Hampshire and White Mountain magma series have been intruded. North of latitude 43° 15' N. this belt is fifty miles wide and extends all the way to the Maine border. South of latitude 43° 15' N. this belt of schists extends eastward to the body of "granite, quartz monzonite, and granodiorite". At the Massachusetts border these schists in the central synclinorium are only twenty miles wide.

The structure of these schists in the central synclinorium is incompletely known. This is partly because much of the area has not been mapped in detail. But even in areas that have been carefully studied the structure is often difficult to decipher because of the lack of horizon markers in the monotonous schists of the Littleton formation.

Within a number of areas the structure of these schists is well known. For example, in the Monadnock quadrangle (E8), which is on the west margin of the central synclinorium, the structural details are superbly displayed on the barren upper slopes of Mt. Monadnock. A major synclinal axis lies 0.2 mile east of the summit of the mountain, whereas a major anticlinal axis lies 0.6 mile west of the summit. Both folds plunge northeast. Numerous minor folds may be seen in individual outcrops. Moreover, a thin belt of lime-silicate granulite and rusty quartzite in the central part of the quadrangle shows a very sinuous map-pattern, indicative of folds. Two major anticlines, the axes of which are about four miles apart, plunge northeasterly. Small to medium-sized bodies of plutonic rocks are abundant.

A major pluton, composed of the Kinsman quartz monzonite, lies along the western margin of the central synclinorium. This, one of the largest plutons in New Hampshire, is nearly 60 miles long, averages 8 miles in width, and occupies approximately 450 square miles. In its broader features it is concordant, for it strikes parallel to the regional structure; the contacts, in general, are parallel to the bedding of the adjacent schists. The body thus appears to be a huge sheet in the schists of the western limb of the central synclinorium. At the north, in the Cardigan quadrangle (B9), this sheet dips 30° east, but toward the south it dips very steeply toward the east. At the extreme south end, in the Monadnock quadrangle (E8), it may be cross-cutting.

Two smaller bodies of Kinsman quartz monzonite appear along the strike to the north.

Lake Winnipesaukee lies in the midst of a large irregular elliptical pluton of Winnepesaukee quartz diorite and Kinsman quartz monzonite. The long axis, trending northwest, is 26 miles long, the short axis, trending northeast, is 22 miles long. This body originally covered about 430 square miles, but its area has been reduced

considerably by the emplacement of several stocks of the younger White Mountain magma series. Along its northern margin this large pluton is concordant with the adjacent schists of the Littleton formation. Relations elsewhere have not been studied or are obscured by the intrusives of the younger White Mountain magma series.

Fitchburg pluton. A large body of plutonic rocks, labeled "granite, quartz monzonite, and granodiorite", trends northeasterly across New Hampshire between the Littleton formation and the Merrimack group. This belt is continuous with the Fitchburg granite of Massachusetts, hence it is here proposed to call the whole body the Fitchburg pluton. It should be noted, however, that Emerson's Fitchburg granite included two very contrasting types of rocks, an older gray gneissic granite and a younger binary granite. Detailed studies in the Fitchburg pluton in New Hampshire have been confined to the Mt. Pawtuckaway quadrangle, which lies between longitudes 71° 00' W. and 71° 15' W.

In the Mt. Pawtuckaway quadrangle Freedman mapped three major types of rock within this belt: (1) quartz-monzonite — "light-gray to dark-gray, medium-grained to coarse-grained, massive to foliated quartz monzonite and granodiorite"; (2) binary granite — "white to light-gray, medium-grained to coarse-grained, massive to faintly foliated granite and quartz monzonite"; and (3) microcline granite — "pink to light-gray, massive to foliated, medium-grained to coarse-grained granite". He thought that these rocks had been emplaced by magmatic stoping. Reconnaissance studies further south in this belt by Billings and Heald in 1951 indicated that gray to pink granite gneisses were the most common type of rock, many of which appeared to be migmatites.

Rockingham anticlinorium. The Merrimack group and the Rye formation of southeastern New Hampshire have been deformed into a series of folds trending northeast-southwest. It is here proposed to call this entire belt the Rockingham anticlinorium. The structure has been studied in greatest detail north of latitude 43° 00' N.

The oldest rocks are exposed near the coast, where the Rye formation is brought up in the core of the Rye anticline. Reconnaissance by Billings and Heald in 1951 indicates that the Rye anticline plunges southeast, consequently the lower mica schist member of the Rye formation, the upper volcanic member of the Rye formation, and the Kittery formation disappear progressively further to the southwest.

The Great Bay syncline, likewise trending northeast-southwest, lies to the northwest and is occupied by the Eliot formation.

The Exeter diorite has been intruded into a northeasterly trending anticline, because the Kittery quartzite southeast and northwest of the diorite is flanked by the Eliot formation.

Northwest of the Exeter diorite the strata form a vertical homoclinal sequence that trends northeast. The Eliot formation lies northwest of the Kittery quartzite and still further to the northwest is the Berwick formation. Despite numerous minor folds the strata are in general progressively younger toward the northwest up to the belt of "granite, quartz monzonite, and granodiorite". Freedman says that 80 per cent of the minor folds indicate that the top is toward the northwest.

Seabrook thrust. In the extreme southeast corner of the map (Plate 4) the pre-Cambrian Newburyport quartz diorite is shown as thrust northward over the Merrimack group. This is a tentative suggestion, as the relationship between these two groups must be solved in Massachusetts.

White Mountain magma series. The rocks of the White Mountain magma series are not only exposed in the White Mountain batholith -- the southern margin of which is shown along the northeastern margin of Plate 4 -- but also in numerous stocks and ring-dike complexes. Considering all of New England and southern Quebec, it is apparent that these bodies are not confined to any one of the tectonic belts defined by the older rocks. In fact, bodies of this series appear in all the tectonic units. Some of the Monterogian Hills of Canada -- which are held up by rocks of the White Mountain magma series -- lie in the foreland of the Appalachian belt. The stock at Cuttingsville, Vermont, cuts the Green Mountain anticlinorium. Mt. Ascutney, Vermont, intrudes the east flank of the Chester dome. In northern New Hampshire, rocks of the White Mountain magma series cut the Connecticut Valley belt of folds and faults, as well as the Bronson Hill anticline. In that part of New Hampshire covered by Plate 4 the White Mountain magma series is extensively developed in the central synclinorium. Small bodies cut the Fitchburg pluton and the Rockingham anticlinorium. Additional bodies are found further south in Massachusetts.

Origin of Plutonic Rocks

General statement. In recent years a great deal of argument has developed over the origin and mechanics of emplacement of plutonic rocks. The concept of extensive granitization has even been applied to New England (Currier, 1947). Hence some consideration of this problem is desirable.

Highlandcroft magma series. Within the limits of Plate 4 the Highlandcroft magma series plays a distinctly minor role. Further north in New Hampshire it is clear that the rocks of this series were intruded as magma. Dikes of this series cut the older rocks; moreover, angular inclusions of the country rocks are not uncommon in the plutonic rocks.

Oliverian magma series. At the present time there is no unanimity on the structure or origin of these rocks. There is, of course, complete agreement that this series occurs as the cores of domes about which the Ordovician (?), Silurian, and Devonian rocks are concentrically distributed. It is also clear that the plutonic rocks are essentially concordant with the overlying formations. Billings, G. E. Moore, and F. C. Kruger believe that the various units of this series were intruded as magma to form a single horizontal composite sheet prior to the main orogeny. They believe that the domes are anticlines formed when this sheet was later folded. C. A. Chapman believes that the domes are separate laccoliths that were later deformed. J. B. Hadley, who originally considered the domes to be syntectonic phaccoliths, has recently suggested that the Oliverian series is the result of "synkinematic granitization in anticlinal structures."

New Hampshire magma series. Everyone who has studied these rocks in the field and has published his observations agrees on two major points.

(1) This series is essentially syntectonic. The mafic rocks (originally diorites or diabases) are now metamorphosed to amphibolites in the zones of higher metamorphism. The Bethlehem, Kinsman, and the quartz diorites (Winnipesaukee and Spaulding) are granulated and in many places show a secondary lineation. The binary granites (Concord) are essentially undeformed and hence are considered to be late tectonic.

(2) The early mafic dikes, the Bethlehem, Kinsman, Winnipesaukee, Spaulding, and Concord were emplaced as if they were magma. The early mafic members formed dikes, sills, and small stocks. The main bodies, notably the Bethlehem gneiss, the Kinsman quartz monzonite, and the quartz diorites are concordant bodies; many of them are large sheets. Dikes and sills in the older rocks, as well as angular inclusions of the country rock in the plutonic rocks, indicate magmatic conditions. The binary

granites may have been emplaced in part by magmatic stoping.

The origin of the magmas, however, is a matter of conjecture. Items to which some consideration should be given are: (a) fractional crystallization of basalt; (b) melting of older plutonic rocks (Quinn, 1944); or (c) migmatization of sediments and their upward movement into their present position as a partial liquid (Billings, 1945; Hadley, 1951).

White Mountain magma series. Every one familiar with these rocks in the field agrees that they consolidated from magma. The extensive development of surface volcanics (Moat volcanics) is one line of evidence. The structural relations of the plutonic rocks -- ring-dikes and numerous angular inclusions -- are additional evidence.

Orogeny

The major orogeny in New Hampshire was Acadian (middle and/or Late Devonian). The sequence of events was as follows: (1) folding of rocks as young as lower Devonian (Littleton formation), accompanied by the emplacement of the New Hampshire magma series; (2) deep erosion; (3) eruption of the Moat volcanics (Mississippian (?)). Hence the orogeny took place between the lower Devonian and the Mississippian (?).

Evidence of the Taconic (late Ordovician) orogeny is found chiefly in the Littleton-Moosilauke area, where the Silurian rests unconformably on the older rocks.

There is no evidence that the Appalachian revolution, so important in southeastern New England, affected New Hampshire.

Some of the normal faults of western New Hampshire are Triassic. In particular, the large fault bounding the Kinsman quartz monzonite on the southeast in the extreme southwest corner of the state is the northward continuation of the fault that bounds the Triassic rocks of northern Massachusetts on the east.

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TABLE 1

STRATIGRAPHY OF FLAT-LYING PALEOZOIC ROCKS

Saratoga Springs (D1) (Cushing and Ruedemann, 1914; Fisher and Hanson, 1951)	Ticonderoga (A3) (Rodgers, ms.)
MIDDLE ORDOVICIAN	
(Thickness in feet)	(Thickness in feet)
Schenectady formation---------2,000± Grit, sandstone, black and gray shale.	
Canajoharie shale-------------1,000± Soft black carbonaceous, partly calcareous shale.	Canajoharie shale---------500+ Black mainly calcareous shale, some argilaceous limestone below.
Trenton limestone------------50 to 80 Thin-bedded limestone, argillaceous and shaly above, mainly "crystalline" below.	Glens Falls limestone---- 60 Dark "crystalline" nodular limestone, shaly above.
Lowville and Amsterdam limestones ----------- 0 to 4 Thick-bedded fine-grained limestone.	Orwell ("Black River") limestone --------------- 60 Dark fine-grained even-bedded limestone, nearly free of silt and clay.

TABLE 1

MIDDLE ORDOVICIAN (cont.)

(Thickness in feet)	(Thickness in feet)
(Missing)	Chazy (Crown Point) limestone.------------------ 0 to 100 Impure limestone with much silty dolomite as wisps and thin seams.

LOWER ORDOVICIAN

(Thickness in feet)	(Thickness in feet)
Gailer dolomite-------------- 150 Massive cherty gray dolomite, locally sand; basal sandstone.	Beekmantown dolomite-------- 1,300 Gray fairly crystalline dolomite, middle part highly cherty and including beds of fine-grained sandstone. (Basal part of unit may include some Cambrian).
Ritchie limestone-----------0 to 43 Massive aphanitic limestone. (Age uncertain, may be facies of beds above or below).	

UPPER CAMBRIAN

Hoyt limestone------------- 55 Thick-bedded limestone and dolomite, with cryptozoön reefs, oölite, and sandstone layers.	"Little Falls" dolomite--- 250 Crystalline dolomite, dark and sandy below, light and cherty above; layers of limestone with cryptozoön above, of sandstone below.
Galway ("Theresa") formation-- 120 Sandy dolomite, dolomitic sandstone, and vitreous quartzitic sandstone.	Potsdam sandstone------------- 400? Vitreous quartzitic sandstone, some dolomitic sandstone and sandy dolomite above.
Potsdam sandstone------------- $100^{\pm}$ Sandstone, mainly quartzitic below, dolomitic above.	

PRE-CAMBRIAN

Gneiss and schist intruded by granite and syenite.	Gneiss and schist intruded by granite and syenite.

TABLE 2

STRATIGRAPHY OF WESTERN BELT OF DEFORMED CARBONATE ROCKS

Fort Ann (C3) (Flower, ms.)	Shoreham (A3) (Cady, 1945)

MIDDLE ORDOVICIAN

(Thickness in feet)	(Thickness in feet)
Snake Hill shale------ 600^{+} Black and gray, partly silty and sandy shale and slate.	Hortonville slate ---------- 400^{+} Blue-black slate, locally quartzitic.

TABLE 2

MIDDLE ORDOVICIAN (cont.)

(Thickness in feet)	(Thickness in feet)
Glens Falls limestone -- Nodular "crystalline" limestone.	Glens Falls limestone------ 115 Dark "crystalline" thin-bedded to nodular shaly limestone.
Orwell limestone ------- Dark fine-grained limestone.	Orwell limestone ---------- 60? Black fine-grained relatively pure and massive limestone.
(Missing)	Crown Point limestone ----- 200- Gray impure fairly massive limestone, with very irregular silty dolomite partings.

LOWER ORDOVICIAN

Providence Island dolomite-- 200 Gray dolomite, thin limestone beds near top.	Bridport dolomite --------- 470 Gray fine-grained uniform dolomite.
Fort Cassin formation ------ 150 Interbedded limestone and dolomite, basal sandstone.	Bascom formation ---------- 375 Limestone, dolomite, and sandstone in alternating layers, the carbonate rocks commonly sandy.
Smith Basin formation ------- 90 Cherty dolomite with some limestone layers below.	
(Missing?)	Cutting dolomite ---------- 350 Gray cherty dolomite, with prominent basal cross-bedded sandstone.
Great Meadows formation ----- 110 Mainly dolomite, persistent limestone layer at top (Fort Ann limestone), lenses below prominent basal cross-bedded sandstone.	Shelburne "marble" -------- 295 Light gray fairly massive dolomite, also blue limestone in part laterally equivalent to dolomite.
Baldwin Corner formation----- 120 Gray or yellow earthy fine-grained dolomite; fairly persistent limestone layers near middle and at base.	(Missing or mapped with Shelburne).

UPPER CAMBRIAN

Whitehall formation --------- 115 Light generally cherty dolomite, upper part commonly replaced laterally by limestone (Hoyt limestone); cryptozoön layers.	Clarendon Springs dolomite -- 310 Gray crystalline dolomite, darker below, lighter and cherty above, thin sandstone beds near top.
Dewey Bridge dolomite ------- 200 Dark gray crystalline and sandy dolomite; cryptozoön layers above and thin sandstone at top.	

TABLE 2

UPPER CAMBRIAN (cont.)

	(Thickness in feet)		(Thickness in feet)
Potsdam sandstone	300	Danby formation ("Potsdam sandstone")	400±
Vitreous quartzitic sandstone, with thin beds of dolomitic sandstone and sandy dolomite near middle.		Vitreous quartzitic sandstone, also dolomitic sandstone and sandy dolomite, especially above.	

TABLE 3

STRATIGRAPHY OF TACONIC SEQUENCE

ORDOVICIAN (MIDDLE AND LOWER)

	(Thickness in feet)
Normanskill formation	1,250 - 2,500
Dark gray silty and sandy shale and black carbonaceous shale, with numerous layers of calcareous grit or graywacke and of white-weathering chert, also lenses or a layer of red slate to north; contains lenses of polymikt limestone-conglomerate (Rysedorph Hill conglomerate) along or west of western border of Taconic belt proper. Named near Albany; present throughout belt.	
Deepkill shale	200 - 300
Green and gray siliceous shale, with thin layers of black shale, limestone, limestone-conglomerate, and calcareous quartzite or grit. Named near Troy; not yet mapped north of Rensselaer county, New York, though fossils have been found in several places near Granville, New York (C-3).	
Schaghticoke shale (pronounced skat-i-coke)	30+
"Lithologically identical" with Deepkill shale (Ruedemann, 1930, p. 85). Named north of Troy; mapped only there and near Schuylerville, where it is west of Taconic belt proper, but fossils have been found near Granville, New York (C-3), and Fair Haven, Vermont (B-3).	

CAMBRIAN (LOWER)

Zion Hill quartzite (Eagle Bridge quartzite may be equivalent)	0-100
Ferruginous quartzite or calcareous sandstone. Named near north end of belt; present locally through much of belt (Eagle Bridge quartzite named northeast of Troy). Thought by some to be basal Ordovician.	

TABLE 3

CAMBRIAN (LOWER) (cont.)

(Thickness in feet)

Wallace Ledge formation -- 0-100
Green and purple slate.
Named near north end of belt; recognized only close to type area.

Schodack formation (in strict sense also called Schodack shale and limestone) ------------------------------------ 200±
Black and dark gray shale (also greenish to south), with thick and thin beds of limestone and limestone-conglomerate, and thin beds of calcareous sandstone and quartzite.
Named near Albany; present throughout belt.

Eddy Hill grit -- 0 - 40
Dark gray calcareous grit with black slate fragments.
Named near north end of belt; present locally as far south as Schuylerville.

Mettawee slate (Troy shale may be equivalent) ------ Mettawee 200+
Troy 100-
Light green, purple, and red roofing slate and shale, with beds of calcareous quartzite and limestone-conglomerate.
Named in north part of belt; apparently present throughout, being represented to south either by Troy shale or in upper Nassau beds.

Diamond Rock quartzite -- 0 - 40
Lenses of granular quartzite and calcareous sandstone at Troy and perhaps elsewhere.

Bomoseen grit ------------------------------ to north 200 - 500
to south 20 - 50
Olive-green grit, weathering pale red, with some beds of greenish slate.
Named near north end of belt; apparently present throughout.

Nassau beds (rocks mapped as Berkshire and Rowe schists are probably in part equivalent) -------- 1,000±
Greenish and reddish shale, slate, and phyllite, with thin and thick beds of greenish quartzite and grit.
Named near Albany; not yet recognized in Washington County, New York, but possibly in part included in Bomoseen grit or even Mettawee slate there.
Classed by some as pre-Cambrian (?)

GRITS OF UNCERTAIN AGE

Rensselaer and Bird Mountain grits or graywackes ----- 500 - 1,400
Fine to coarse dark greenish polymikt grit or graywacke, locally graywacke-conglomerate; also beds of green, purple, and red slate and shale.
Rensselaer named east of Troy; Bird Mountain near north end of belt.

TABLE 4

FORMATIONS OF VERMONT VALLEY SEQUENCE

(Eastern belt of deformed carbonate rocks)

MIDDLE ORDOVICIAN

	(Thickness in feet)
Hortonville formation	600
Gray to black slate or phyllite.	
Whipple marble	300
(Possibly equivalent, in part, to Orwell and Middlebury limestones.)	
Thin-bedded, blue-gray granular limestone; fine-grained black limestone; beds of black phyllite in upper part and of dark gray dolomite in lower part. Near Danby includes greenstones and light-colored feldspathic schists of probable volcanic origin.	
Orwell limestone	0 - 50
Fine-grained black limestone.	(Fowler, 1951)
Middlebury limestone	0 - 60
	(Fowler, 1951)
Thin-bedded, blue-gray granular limestone, with dolomite beds near base.	

LOWER ORDOVICIAN

Beldens formation	0 - 200
	(Fowler, 1951)
Beds of dolomite one to three feet thick interbedded with white and blue-gray limestone.	
Burchards formation	0 - 150 (?)
	(Fowler, 1951)
Banded gray and white marble with thin beds of dolomite.	
Bascom formation	0 - 500 (?)
	(Fowler, 1951)
Blue-gray and white banded marble with beds of dolomite, sandstone and phyllite.	
Boardman formation	500-600
Columbian marble member: white and blue-gray marble with dolomitic "curdling."	(250)
Intermediate dolomite member: massive gray dolomite.	(200)
Sutherland Falls marble member: white and blue-gray marble with dolomitic "curdling."	(50-100)

UPPER CAMBRIAN

Clarendon Springs dolomite	70-100
Massive gray dolomite.	
Danby formation	200-250
Dolomite and sandy dolomite with beds of pure, vitreous quartzite up to five feet thick.	

TABLE 4

LOWER OR MIDDLE CAMBRIAN

	(Thickness in feet)
Winooski dolomite --	300 - 400
Buff and gray dolomite in beds up to one foot thick separated by thin siliceous partings.	

LOWER CAMBRIAN

Monkton quartzite --	300
Red or gray-green quartzite interbedded with dolomite, sandy dolomite and thin beds of gray-green or black phyllite.	
Dunham dolomite --	900
Upper part: cross-bedded sandy dolomite and dolomitic sandstone (Mallett member).	
Lower part: massive gray and buff dolomites.	
Cheshire quartzite --	300-700
Pure, white, massive quartzite with thin beds of gray to black sandy phyllite in lower part.	
Mendon series --	450-1100
Upper part: gray to black quartzose phyllite with massive beds of pure or slightly arkosic white quartzite (Moosalamoo phyllite).	(400-800)
Lower part: conglomerate, graywacke, arkose and micaceous quartzite with discontinuous beds of dolomite near top. (Pinnacle arkose).	(50-300)

PRE-CAMBRIAN

Mount Holly series --	Unknown
Schist, gneiss, quartzite, amphibolite, marble, and calc-silicate rocks.	

TABLE 5

FORMATIONS OF EASTERN VERMONT SEQUENCE

MIDDLE ORDOVICIAN OR YOUNGER

	(Thickness in feet)
Orfordville formation (See table 6) ------------	
Gile Mountain formation --	0-5000?
Gray to black phyllite, quartzose phyllite and micaceous quartzite with thin beds of limestone. In higher metamorphic grades phyllites become schists containing biotite, garnet, and staurolite.	
Standing Pond volcanics --	1,000
Greenstone schists and light colored feldspathic schists, metamorphosed in garnet and staurolite zones to amphibolite and hornblende-garnet gneiss.	

TABLE 5

MIDDLE ORDOVICIAN OR YOUNGER (cont.)

	(Thickness in feet)
Waits River formation	5000?
Limestone interbedded with gray to black phyllite. In higher metamorphic grades phyllites become schists containing biotite, garnet, staurolite, and kyanite.	
Northfield formation	700
Gray to black slate or phyllite. In higher metamorphic grades phyllites become schists containing biotite, garnet, staurolite, and kyanite.	
Shaw Mountain formation	0 - 500
Quartzite, quartz-conglomerate, limestone, mica schist, and greenstone schists metamorphosed locally to amphibolite. White and Jahns (1950) report metamorphosed rhyolite tuff.	

MIDDLE ORDOVICIAN

Cram Hill formation	6000
Quartzite and gray to black, rusty-weathering phyllite or schist, interfingering laterally with biotite gneiss, hornblende gneiss and amphibolite (Barnard gneiss member) believed to be metamorphosed volcanics.	

CAMBRIAN OR EARLY ORDOVICIAN

Moretown formation	3700
Gray-green micaceous quartzite, quartz-muscovite-chlorite schist and greenstone schist. In higher metamorphic grades mica schists may contain biotite, garnet, staurolite, or kyanite, and greenstones are metamorphosed to epidote-amphibolites.	
Stowe formation	900
Lithologically identical to upper part of Pinney Hollow formation.	
Ottauquechee formation	1400
Thick-bedded quartzite and black phyllite interbedded with rocks similar to upper part of Pinney Hollow formation.	
Pinney Hollow formation	3000
Gray-green, quartz-sericite-chlorite schist or phyllite, interbedded in upper part with greenstone schists. In higher metamorphic grades schists may contain biotite, chloritoid, garnet, staurolite, or kyanite, and greenstones are metamorphosed to epidote-amphibolites.	
Hoosac formation	2700
Gray or black schist with abundant (10-12%) porphyroblasts of albite. Gray-green quartz-sericite-chlorite schist in lenses near base.	

TABLE 5

CAMBRIAN OR EARLY ORDOVICIAN (cont.)

	(Thickness in feet)
Hoosac formation (cont.)	
Albite schists contain biotite and garnet in higher metamorphosed grades. Non-albitic schists near base contain abundant staurolite and kyanite in Chester dome (Gassetts schist).	
Plymouth member	(1000)
Quartzite and dolomite. (In upper part of Hoosac formation. Plymouth member disappears south of Ludlow).	
Turkey Mountain member	(0-1000, not present at Ludlow)
Greenstone (amygdaloidal) and greenstone schist, metamorphosed locally to epidote-amphibolite. (At approximate position of Plymouth member in Chester dome and on east limb of Green Mountain anticlinorium from Jamaica south.)	
Bull Hill member	(0-1000, not present at Ludlow)
Microcline augen gneiss believed to be metamorphosed rhyolite and rhyolite tuff. (Near base of formation in Chester dome and on east limb of Green Mountain anticlinorium from Jamaica south.)	
Tyson formation	0-600
Conglomerate, graywacke, schist and micaceous quartzite with lenses of calcite and dolomite marble at top. Marbles are metamorphosed in part to diopside-actinolite granulite in Chester dome.	

PRE-CAMBRIAN

Mount Holly series	Unknown
Schist, gneiss, amphibolite, marble and calc-silicate rock.	

TABLE 6

METASEDIMENTARY AND METAVOLCANIC ROCKS OF SOUTHERN NEW HAMPSHIRE

A. WESTERN AND CENTRAL PART OF STATE

	(Thickness in feet)
LOWER DEVONIAN	
LITTLETON FORMATION	15,000
Metasedimentary rocks that were originally shales and argillaceous sandstones	
Biotite zone: phyllite, quartzose phyllite, and quartzite, all of which contain porphyroblasts of biotite.	
Garnet zone: phyllite and quartzose phyllite, both of which may contain porphyroblasts of biotite and/or garnet.	

LITTLETON FORMATION (cont.) (Thickness in feet)

Staurolite zone: mica schist, mica-quartz schist, quartz-mica schist, and quartzite, all of which may contain porphyroblasts of biotite, garnet, and/or staurolite.

Sillimanite zone: quartz-mica schist, sillimanite schist, mica-quartz schist, quartz-mica schist, and quartzite; such minerals as biotite, garnet, and sillimanite are commonly present. In places areas of paragneiss are separately designated.

Metasedimentary rocks that were originally impure dolomites

Staurolite and sillimanite zones: biotite-amphibole granulite, actinolite granulite, diopside-actinolite granulite.

Metasedimentary rocks that were originally relatively clean quartz sandstones and quartz conglomerates

Staurolite and sillimanite zones: white quartzite and quartz conglomerate.

Metavolcanic rocks

Staurolite zone: amphibolite and fine-grained biotite gneiss.

MIDDLE SILURIAN

FITCH FORMATION 0-600

Staurolite and sillimanite zones: calcareous quartz-mica schist, marble, biotite-actinolite schist, diopside-garnet granulite, diopside-feldspar granulite, actinolite-feldspar granulite, tremolite-quartz feldspar granulite, and quartzite.

LOWER OR MIDDLE SILURIAN

CLOUGH QUARTZITE 0-300

Staurolite and sillimanite zones: white quartzite, some white quartz conglomerate and some white muscovite schist; the accessory minerals in the muscovite-quartz schist depend upon the metamorphic zone; they are biotite, garnet, staurolite, or sillimanite.

- - - - Major Unconformity - - - -

UPPER ORDOVICIAN (?)

PARTRIDGE FORMATION 0-1000

Staurolite zone: mica schist, garnet-mica schist, staurolite-mica schist, quartz-mica schist, and micaceous quartzite.

Sillimanite zone: mica schist, garnet-mica schist, sillimanite-garnet schist, micaceous quartzite.

AMMONOOSUC VOLCANICS 100-2,000

Staurolite and sillimanite zones: fine-grained light-colored biotite gneiss and amphibolite.

ALBEE FORMATION 5,000±

Chiefly staurolite zone: generally light-colored quartzite, quartz-mica schist and mica schist, including such minerals as biotite, garnet and/or staurolite.

TABLE 6

MIDDLE ORDOVICIAN (?) (Thickness in feet)

ORFORDVILLE FORMATION 4000±

Metasedimentary rocks that were originally shale and argillaceous sandstone

Chlorite zone: slate, black phyllite, and quartzite.

Biotite zone: gray phyllite, black phyllite and quartzite, all three of which may contain porphyroblasts of biotite.

Garnet zone: gray phyllite and black phyllite, both of which may contain porphyroblasts of biotite and/or garnet.

Metasedimentary rocks that were originally clean quartz sandstones and quartz conglomerates. Hardy Hill quartzite member (0-250 ft. thick).

Chlorite zone: greenish gray quartzite and quartz conglomerate.

Biotite zone: white quartzite and quartz conglomerate with occasional biotite porphyroblasts.

Garnet and staurolite zones: quartzite and quartz conglomerate, with minor amounts of quartz-mica schist and a mica schist which may contain porphyroblasts of garnet and/or staurolite.

Metavolcanic rocks - Post Pond volcanic member

Biotite zone: albite-epidote amphibolite, fine-grained biotite gneiss, and some mica schist.

Garnet zone: amphibolite, amphibole gneiss, fine-grained biotite gneiss, and some quartz-mica schist.

GILE MOUNTAIN FORMATION
(See table for Vermont)

STANDING POND VOLCANICS
(See table for Vermont)

B. SOUTHEASTERN PART OF STATE

PALEOZOIC: These rocks have been assigned to the Pennsylvanian by the U. S. Geol. Survey. In Massachusetts it is now recognized that these rocks are unconformable beneath the Worcester phyllite which is considered to be probably Pennsylvanian. Hence, the formations listed below are probably Pre-Pennsylvanian. J. Freedman considers them to be probably Silurian.

MERRIMACK GROUP

Chlorite zone: buff slate, buff sandstone, and gray calcareous slate; dark-gray phyllite shown by special pattern.

Biotite zone: purplish-brown schist, gray quartz-mica schist, greenish gray actinolite granulite and brown biotite-actinolite schist.

Garnet, staurolite, and sillimanite zones: similar to biotite zone, except that garnet is also present. Coarse-grained gray mica schist is shown by a special pattern.

PALEOZOIC (cont.) (Thickness in feet)

North of a line corresponding approximately to latitude 43° 00' N. the Merrimack group has been divided into the Kittery, Eliot and Berwick formations.

BERWICK FORMATION 7,000

Chlorite zone: buff slate, buff siltsone, and gray calcareous slate.

Biotite zone: purplish-brown biotite schist, gray quartz-mica schist, greenish gray actinolite granulite, and brown biotite-actinolite schist.

Garnet, staurolite and sillimanite zones: similar to biotite zone except that garnet is also present. Gove member is chiefly a silvery mica-schist, some of it containing staurolite and/or sillimanite.

ELIOT FORMATION 6,500

Chlorite zone: buff slate, buff siltstone, and gray calcareous slate. Calef member is chiefly black phyllite; some gray quartz-phyllite.

Biotite zone: purplish brown biotite-schist, gray quartz-mica schist, greenish gray actinolite granulite and brown biotite-actinolite schist.

KITTERY QUARTZITE 1,500+

Chlorite zone: gray quartzite, argillaceous quartzite, and slate.

Biotite zone: similar to rocks in chlorite zone except that some biotite porphyroblasts are present.

PALEOZOIC: The following formation is considered Algonkian (?) by the U. S. Geol. Survey. It appears to be conformable with the overlying Merrimack group. It may be in part equivalent to the Ammonoosuc volcanics in the western part of the state.

RYE FORMATION 4,000±

Upper metavolcanic member

Biotite zone: fine-grained biotite gneiss and amphibolite, both of which may contain garnet.

Lower metasedimentary member

Garnet zone: feldspathic mica schist with biotite and garnet.

Staurolite zone: feldspathic mica schist with biotite, garnet and staurolite.

Sillimanite zone: feldspathic mica schist with biotite, garnet and sillimanite.

TABLE 7

PLUTONIC AND VOLCANIC ROCKS OF SOUTHERN NEW HAMPSHIRE

MISSISSIPPIAN (?)

WHITE MOUNTAIN MAGMA SERIES

A plutonic-volcanic complex consisting of gabbro, diorite, monzonite, syenite, nephelite-sodalite syenite, quartz syenite, amphibole granite, and biotite granite; also basalt, andesite, trachyte, and rhyolite. The various units of the White Mountain magma series have not been separately distinguished on Plate 4.

LATE DEVONIAN (?)

NEW HAMPSHIRE MAGMA SERIES

Binary granite: medium-grained white to light-gray biotite-muscovite granite. Includes Concord granite. Also includes some biotite granite, some of which is cataclastic.

Granite, quartz monzonite, and granodiorite: Where mapped in detail, east of longitude 71° 15' W., these rocks are pink to gray, medium-grained to coarse-grained, massive to foliated microcline granite, quartz monzonite, and binary granite. West of longitude 71° 15' W., where these rocks have not been mapped in detail, some areas of schist have not been distinguished. Some areas of migmatites. Continuous with Fitchburg granite of Massachusetts.

Ayer granodiorite: Medium-grained to coarse-grained gray biotite-hornblende granodiorite, in many places with phenocrysts of potash feldspar 1 to 3 inches long.

Kinsman quartz monzonite: Dark-gray to light-gray, medium-grained to coarse-grained biotite-quartz monzonite; in many places with phenocrysts of potash feldspar 1 to 3 inches long; massive to well-foliated. Includes Meredith granite of Lake Winnipesaukee region.

Bethlehem gneiss: Dark-gray to light-gray medium-grained biotite gneiss, strongly to weakly foliated; granoblastic texture common. Chiefly granodirite, some quartz diorite and quartz monzonite.

Quartz diorite: Includes Winnipesaukee quartz diorite of central part of state and Spaulding quartz diorite of southwestern part of state. Dark-gray to gray medium-grained biotite - quartz diorite; massive to well-foliated; includes some diorite, granodiorite, and quartz monzonite.

Diorite: Includes Exeter diorite. Medium-grained to coarse-grained dark-gray diorite. Includes some quartz diorite, granodiorite, and quartz monzonite; locally foliated.

MIDDLE DEVONIAN (?)

OLIVERIAN MAGMA SERIES (?)

Lebanon granite: Medium-grained to coarse-grained sub-porphyritic somewhat granulated biotite granite.

Border gneiss: fine-grained to medium-grained dark-gray granulated gneiss ranging from gabbro to quartz monzonite.

TABLE 7

OLIVERIAN MAGMA SERIES

Pink to gray granite, quartz monzonite and granodiorite. In many places foliated and granoblastic, elsewhere massive. Depending upon the ratio of potash feldspar to total feldspar the rocks are granite, quartz monzonite, and granodiorite, rarely quartz diorite.

LATE ORDOVICIAN (?)

HIGHLANDCROFT MAGMA SERIES

Gray to pink coarse-grained quartz monzonite within limits of this map.

Itinerary

East-central New York and Southwestern Vermont

Quadrangles: 15' Albany, Troy, Cohoes, Schuylerville, Cambridge ($7\frac{1}{2}$' Cossayuna),
Fort Ann ($7\frac{1}{2}$' Hartford, Fort Ann, Granville), Whitehall ($7\frac{1}{2}$' Whitehall (unpublished), Thorn Hill), Castleton.
Trip starts at Albany, New York, at corner of Washington Avenue and Hawk Street; this is at north portal of State Capitol and east end of State Education Building.

Mileage

0.0 Proceed north on Hawk Street, crossing viaduct.

0.3 End of viaduct, corner of Hawk and Clinton; turn right on Clinton Avenue.

0.5 Two blocks, corner of Clinton and North Pearl; turn left on North Pearl St. and Route 32. Enter Troy quadrangle.

1.1 Right turn under railroad, then left; continue on North Pearl Street and Route 32.

2.4 - 2.5 Turn right on Wolfert Avenue, then left on Broadway (following Route 32). Broadway is Route 2.

4.2 Turn right, following Route 2 across bridge (Hudson River).

5.6 Keep left, following Route 2 into Troy.

5.9 Bear right on Fourth St., following Route 2.

6.4 Bear right on Fourth St., following Route 2.

7.4 Turn right on Ferry St., following Route 2.

7.6 - 8. 0 Shale outcrops, especially on right. Mainly Snake Hill slate, but under park Normanskill formation appears, and rocks are badly brecciated (Poestenkill breccia of Ruedemann, 1930).

7.8 Enter Congress Street; keep right following Route 2.

8.2 Turn left on 15th Street, which is Route 40. On right before turning is gorge of Poestenkill, in which Troy Shale (type) is exposed thrust over Normanskill formation, with Poestenkill breccia at contact (type).

8.3 Green slate on right, probably Troy shale (Cambrian), lying above "Taconic" thrust fault. From here for forty miles (to Argyle), the route follows this fault closely, crossing and recrossing it.

8.8 Fifteenth Street and Sage Avenue; R.P.I. Campus. Outcrop of Poestenkill breccia under Cambrian slate on south side of Sage Avenue just to west (left), will not be visited on trip. Continue straight on Route 40.

9.0 Cambrian grit in park on right. Route apparently crosses fault at brow of hill beyond.

9.4 Continue across Hoosick Street following Route 40.

9.5 Ordovician siltstone (Snake Hill) on left. Other outcrops at 9.9.

10.0 - 10.1 Turn left around circle, then right on Oakwood Avenue, following Route 40.

10.3 Ordovician chert and slate on right. Enter Cohoes quadrangle.

10.9 - 11.1 Route crosses fault again; dark Cambrian slate with limestone conglomerate (probably Schodack formation) on right.

11.0 - 13.0 Ridge on left is upheld by Cambrian sandstone, mostly ferruginous (ankeritic?), but locally silica-cemented, as at Diamond Rock, opposite 12.2 but not visible from road (type of Diamond Rock quartzite).

13.0 - 13.1 Intersection with Route 142; turn right and then left following Route 40. Mount Rafinesque to right is Ordovician slate in a large area surrounded by Cambrian slate and thought by Ruedemann to be a fenster.

14.1 Dark slate and limestone conglomerate, probably Schodack formation.

14.4 Small quarry on left, in ferruginous sandstone (Cambrian).

14.9 Speigletown; bear left with Route 40.

15.2 Cambrian grit and fine conglomerate on right. Road crosses fault between this outcrop and the next.

Views of Adirondack Mountains. From near Speigletown for more than 40 miles to Stop 2, the road affords on a clear day fine views of the Adirondack Mountains. The first range visible is the Kayaderosseras Range, west of Saratoga Springs; then the Palmertown Range north of Saratoga Springs comes into view. This range is broken 13 miles north of Saratoga Springs by the gorge through which the Hudson River emerges from the mountains; beyond this point it is called the Luzerne Range and it continues west of Lake George. Next northeast is the short mass of French Mountain; then the range culiminating in Pilot Knob east of Lake George. Close to the Pilot Knob range is Putnam Mountain; standing somewhat apart to the east is the easternmost range of the Adirondacks, extending from Battle Hill near Fort Ann (Stop 3) past Whitehall and into Vermont.

15.9 Ordovician slate and grit. Ruedemann reports Normanskill graptolites.

16.3 - 16.6 More Ordovician slate and grit.

16.9 Hamlet of Grant Hollow to right. Road crosses Deep Kill. Taconic fault lies on face of hills behind houses, with Cambrian rocks above, but top of Rice Mountain (south of gorge of Deep Kill) is Ordovician slate in same area as Mount Rafinesque, and in the gorge itself is the type section of the Deepkill shale (Lower Ordovician).

17.7 Village of Melrose; bear left with Route 40.

19.9 Slate outcrops, probably Normanskill.

22.1 Hoosick River at Schaghticoke (pronounced skát-i-coke). Type locality of Schaghticoke shale (basal Ordovician) is in river bed under bridge. Road crosses onto Cambrian rocks east of fault in village and for short distance beyond, but no outcrops are visible from road.

23.1 Junction with Route 67. Continue straight across following Route 40.

24.9 Black slate and grit, probably Normanskill formation.

25.1 Same along road; outcrops at brow of hill across field to right are Cambrian slate across fault.

26.9 More Ordovician slate.

29.6 Village of Easton on right. North tip of area of Cambrian rocks along fault. Enter Schuylerville quadrangle.

30.6 More Ordovician slate and grit. Willard Mountain to right is also Normanskill formation, but probably across fault.

30.9 Village of North Easton. Low ground to left is underlain by thick mantle of lake clay, etc., over Snake Hill slate, in which Hudson River is incised. Flat ground across river is site of battle of Saratoga, 1777, considered the decisive battle of the Revolutionary War. In distance ahead is shaft of victory monument in village of Schuylerville, where Burgoyne surrendered after the battle.

34.5 Dolomite outcrops (Lower Ordovician) along road are at south end of slice five miles long and as much as half a mile wide along Taconic fault. Louse Hill (Schuyler Mountain) to right is Cambrian grit (Bomoseen). Dolomite continues along road for about a mile. Victory monument visible ahead to left.

36.9 Dolomite in hill to right, quarry.

37.3 Intersection with Route 29; keep right following Route 40.

37.7 Batten Kill at Middle Falls. Falls are over dolomite.

38.3 Turn left, following Route 40. Bald Mountain ahead.

38.9 Cambrian grit and quartzite on right, above fault.

39.3 Intersection with dirt road; turn left <u>off</u> Route 40.

40.0 Dolomite on right, in slice.

40.4 - 40.5 Turn right at corner and park in sight of three old lime kilns.

<u>Stop 1</u>. Bald Mountain quarry. See Cushing and Ruedemann, 1914, pp. 75-84, pls. 12-16, and sketch map and sections in pocket; also pp. 108-109, and Ruedemann, 1930, p. 114.

Low ground to the left is underlain by lake clay, etc., over Snake Hill slate (Middle Ordovician). On both sides of road and in woods to right is Beekmantown dolomite (Lower Ordovician; Providence Island dolomite and Fort Cassin formation recognizable). Just in front of main quarries is a screen of black slate (Ordovician?), farther part of which contains pebbles and larger irregular fragments as much as several feet across of limestone of several kinds, also dolomite and other rocks. Quarries are in large masses of pure limestone, badly shattered and brecciated, with some seams of black slate; much at least of this limestone seems to be Middle Ordovician, as are some of the fragments in the screen of black slate. Upper margin of quarry limestone is very irregular, marked by more black slate with limestone fragments; above this, at upper lip of quarries, lies Cambrian slate and grit. Lower Cambrian fossils have been found in shaly limestone in the slate, higher on the hill.

Apparently the rocks between the Snake Hill slate and the Cambrian slate form two slices along the "Taconic" fault. The west slice consists of dolomite clearly belonging to the western carbonate sequence and therefore roughly autochthonous. The east slice consists of the black slate with limestone fragments and the enclosed pure quarry limestone. Ruedemann interpreted the black-slate-with-fragments partly as mylonite along the fault, partly as Rysedorph Hill conglomerate (latter in part retracted in 1930). The Rysedorph Hill conglomerate is a polymikt limestone breccia interbedded in the Normanskill formation west of the Taconic fault just east of Albany, containing pebbles with fossils from Lower Cambrian to Middle Ordovician (Lower Trenton). The suggestion is here advanced that the masses of pure limestone that have been quarried at Bald Mountain are merely mammoth boulders in a piece of Rysedorph Hill conglomerate caught up as a slice along the fault; in other words, the whole east slice is a sedimentary breccia, itself somewhat brecciated along the fault.

The presence of the autochthonous dolomite here renders still more puzzling the large areas of slates of Taconic type west of the Hudson River (forming hills visible across the river from Stop 1). In these slates is the Starks Knob igneous mass, which contains many inclusions of limestone and dolomite like that seen here.

(Busses turn around 0.2 mile beyond stop. Private cars may proceed on around mountain as follows:

40.7 Keep right at corner.

41.2 Turn right at cross roads, onto Cambrian rocks above fault. (Limestone conglomerate is exposed on creek bank on left of road straight ahead, ½ mile beyond cross roads; it was mapped by Ruedemann as Rysedorph Hill conglomerate but more probably it is Deepkill in age.)

41.8 Cross bridge and keep right.

42.6 Turn left onto Route 40; equals mileage 43.8 of this itinerary.)

Return from Stop 1 to Route 40 (same corner as mileage 39.3).

41.7 Turn left onto Route 40.

41.9 - 42.6 Cambrian grit along road.

43.9 Cambrian slate on left.

44.8 Black Cambrian slate on right.

45.1 Black slate and limestone. Enter Cambridge 15' (Cossayuna 7½') quadrangle.

47.3 Dark Cambrian slate on left.

48.0 Black slate with dolomite-ankerite bands on right.

48.1 - 49.4 Descend from line of hills upheld by Cambrian rocks onto lower ground underlain by Ordovician rocks.

48.5 - 49.4 Road cuts in Cambrian slate and grit.

50.0 Black slate with much pyrite on left; probably Ordovician west of fault.

50.7 Village of Argyle; continue straight through, following Route 197. Observe west front of Cambrian hills receding to northeast (right). Route now crosses diagonally belt of deformed autochthonous rocks.

51.5 - 51.7 Bear left with Route 197, then turn right on blacktop road marked Adamsville, Whitehall. Enter Fort Ann 15' (Hartford 7½') quadrangle.

51.8 - 59.7 Outcrops of dark Ordovician Snake Hill slate or shale; fine views of Adirondack Mountains.

57.1 Hamlet of Adamsville; continue straight across Route 196 on blacktop road.

58.9 Sharp bend by farm; note limestone on left of road, then on right. This is southern tip of limestone band seen at Stop 2 and of carbonate rocks in this structural block.

59.7 Stop 2. Enter quarry on right through narrow cut. Cut is in Snake Hill slate; quarry in Orwell limestone; limestone can be seen thrust over slate at far end of cut.
The low-angle thrust fault seen here appears to continue north into a high-angle fault on the west side of the pre-Cambrian block extending from Fort Ann (Stop 3) northward. This high-angle fault appears to be one of the ordinary Adirondack high-angle faults, except that it is downthrown on the west.

Proceed in same direction.

59.9 Intersection with Route 149; turn left.

60.3 - 60.4 Cross Champlain Canal and railroad (grade crossing; this is main line of Delaware and Hudson Railroad) into hamlet of Smith Basin; swing right with Route 149.

61.5 Canajoharie shale on both sides of road; moderate dip. Route here crosses into region of flat-lying Paleozoic rocks west of deformed belt. (Enter Fort Ann 7½' quadrangle.) Hills to right across canal expose Upper Cambrian dolomite and limestone belonging to deformed belt.

62.4 - 62.5 Baldwin Corner. Turn right on U.S. 4. Exposures are Canajoharie shale with gentle dip and no sign of cleavage.

64.5 Village of Fort Ann. Continue through on U.S. 4. Pre-Cambrian rocks in hills across canal to right.

65.3 <u>Stop 3</u>. Battle Hill.

Pre-Cambrian rock of Adirondack Mountains. Highly garnetiferous gneiss. High-angle fault at west side of block must lie just west of outcrop; this is presumed to be same fault as that seen at Stop 2.

Proceed along U.S. 4.

65.6 Crystalline limestone (Pre-Cambrian) showing faint swirls around blocks of amphibolite.

65.8 - 66.5 Red-hearted pyroxene syenite gneiss. Best exposures are at top of hill (mileage 66.2).

66.5 Route crosses fault onto Potsdam quartzite, about at road corner just short of bridge over railroad.

66.7 <u>Stop 4</u>. Exposures of typical Potsdam quartzite (Upper Cambrian) in railroad cut. This is base of Paleozoic sequence here, but contact with Pre-Cambrian appears to be a fault.

67.2 Dewey Bridge on right. Type locality of Dewey Bridge dolomite (Upper Cambrian) is on road leading south from bridge.

67.9 Potsdam quartzite in fields to left; Pre-Cambrian gneiss in bluff across canal to right (what appears to be bedding is foliation). Small offset of contact by a fault upthrown on right (east) -- contact itself probably being a fault upthrown on left (west).

68.3 - 68.5 Pre-Cambrian gneiss on left, along road and railroad and in quarry across railroad.

68.8 Turn right off U.S. 4 onto Route 22; cross canal into Comstock village.

69.0 Gneiss outcrops on both sides. Great Meadows state prison ahead.

69.3 Potsdam quartzite exposures to left.

69.5 Upper Cambrian dolomite on left. Hill beyond is mainly Baldwin Corner formation (basal Ordovician).

70.0 Stop 5. Breccia (sedimentary?) in Baldwin Corner formation.

70.1 - 70.2 Basal sandstone of Great Meadows formation (type area) descends hill on left.

70.3 - 70.4 Fort Ann limestone (top of Great Meadows formation) and basal breccia of Smith Basin formation on left.

70.6 Stop 6. Beyond power station. Smith Basin formation, showing fairly thin alternating beds of limestone and dolomite, also lateral transition.

70.7 - 70.8 Fault produces repetition of section; mass of quartzite is Potsdam or bed within Dewey Bridge; road cut beyond is Dewey Bridge formation.

71.2 Stop 7. Basal sandstone of Great Meadows formation. Note cross-bedding and crumpling.

71.4 Road cut on left is dolomite in upper part of Great Meadows formation; Fort Ann limestone on hill above.

71.6 Smith Basin formation crops out across field to left.

71.9 Fort Cassin formation crops out in hills $\frac{1}{4}$ mile to north (to visit take side road at 72.0).

72.4 Low outcrops of Providence Island dolomite on left. Fault probably just beyond, downthrown on east (normal?); Snake Hill slate beyond under gravel flat.

72.5 Road intersection at edge of gravel flat. Hills of Cambrian slate beyond, east of "Taconic" thrust.

(Busses turn around here. Private cars may proceed to Whitehall by back road short cut as follows:

72.5 Bear left on dirt road off Route 22. Enter Granville $7\frac{1}{2}$' quadrangle.

73.1 Turn left at cross roads.

73.5 Gorge of Mettawee River on right in Snake Hill slate.

74.1 Mettawee River flows along fault with Providence Island dolomite on left bank, Snake Hill slate on right bank. Same fault as 72.4.

74.6 Outcrops of Fort Cassin limestone as road descends steep hill.

74.7 Bear right; Fort Cassin limestone ahead and on left.

74.9 Pavement.

75.1 - 75.3 Suggested stop. Slate in road bank is on east (right) side of fault; flat-lying dolomite higher on bank is on west side. Fault itself is offset from where seen in Mettawee River at 74.1. Hills to east across river are Cambrian slate, beyond "Taconic" thrust.

75.5 Slate outcrop on left; second offset of fault. Reenter Fort Ann $7\frac{1}{2}$' quadrangle.

75.8 Probable fault scarp in dolomite on left; slate outcrop on right behind barn.

76.5 Prominent fault scarp on left. Baldwin Corner formation. Enter Whitehall quadrangle.

77.3 Top of hill. Dewey Bridge dolomite.

77.4 Keep right with pavement.

77.8 Potsdam quartzite; fault just beyond (same as that at 70.7).

77.9 - 78.0 Road cuts in limestone; probably Middle Ordovician limestone unconformable on Smith Basin formation.

78.8 Cross Mettawee River. Tub Mountain nearby to left, Dewey Bridge to Great Meadows formation. Adirondack Mountains beyond to left, Pre-Cambrian rocks. Skene Mountain ahead, rising directly out of Whitehall, consists of Potsdam quartzite, Dewey Bridge formation, Whitehall formation (type), and Baldwin Corner formation (included in original Whitehall, but now separated).

79.1 Keep left at corner.

80.8 Traffic light in Whitehall, turn right onto U.S. 4; equals mileage 83.8 of this itinerary.

Return from 72.5 to U.S. 4 beyond Comstock (Same corner as mileage 68.8).

76.2 Turn right onto U.S. 4. Pre-Cambrian outcrops on both sides of canal as far as 77.1. Somewhat beyond enter Whitehall quadrangle.

80.8 Big quarry on right is in Tub Mountain, in Dewey Bridge and Whitehall formations; Baldwin Corner and Great Meadows formations above. Skene Mountain directly ahead, rising out of Whitehall, consists of Potsdam quartzite, Dewey Bridge formation, Whitehall formation (type), and Baldwin Corner formation (included in original Whitehall, but now separated).

83.3 Village of Whitehall; turn right with U.S. 4.

84.0 Skene Mountain on left; thin quartzite bed behind houses is top of Dewey Bridge formation.

84.1 Hoyt limestone at top of Whitehall formation behind houses.

84.3 Road cut on left in Baldwin Corner formation.

84.5 Road cut in basal sandstone of Great Meadows formation. Quarry on back side of hill in dolomite of Great Meadows formation.

84.8 Bear right off U.S. 4 on Route 272. (Enter Thorn Hill 7½' quadrangle.)

(If Stop 8 is to be omitted, bear left with U.S. 4 and proceed from mileage 88.2 below. Note two knolls on right, described in first two entries below.)

85.1 First knoll on left; dolomite in Smith Basin formation.

85.3 Second knoll on left; Potsdam quartzite, thrust over Smith Basin formation on same fault as that at 70.7, cut off behind by same fault as at 72.4; beyond is Snake Hill slate.

86.0 Snake Hill slate in road cut on left; also behind farm.

86.2 Middle Ordovician limestone in thrust slice within slate, on hill to left.

86.5 Stop 8. Taconic fault. Ordovician limestone and black slate in road cut; Cambrian gritty slate in outcrop above. In this area, the Taconic rocks come closest (about 3 miles) to the Pre-Cambrian rocks of the Adirondack Mountains, visible to west across valley underlain by rocks of western carbonate sequence.

(Turn around; busses proceed 1.3 miles to triangle at East Whitehall to turn around.)
Return to U.S. 4 (same corner as mileage 84.8).

88.2 Turn very sharp right onto U.S. 4.

89.4 Snake Hill slate in field to right.

89.7 Snake Hill slate in road cut to left.

90.0 - 90.6 Cambrian grit and gritty slate in road cuts.

90.6 Stop 9. Cambrian grit and quartzite; presumably Bomoseen grit.

90.8 - 91.1 Stop 10. Busses proceed to end of road cut. Sequence of rock types in cut:

Silty green slate.
Gradation into dark silty banded slate showing sharp folding, and more carbonate (first ankerite, then dolomite and calcite); also beds of ferruginous quartzite and sandstone.
Dolomite and black slate in alternating bands.
Sharp contact with soft green roofing slate; quarry to left beyond road cut.
First outcrop on right beyond road cut is black slate with thin bed of ferruginous sandstone.

Interpretation: Despite folding, structure is straight-forward and beds are apparently right-side up. Grit at Stop 9 should be Bomoseen, silty green slate Mettawee, and dark slate with dolomite Schodack (lower Cambrian fossils reported half a mile north along strike by Dale, 1899). But green quarry slate is typical Mettawee, and black slate beyond and at Stop 11 is typical Schodack (fossils beyond crest of farther hill). Yet the two belts of green slate are unlike and cannot be the same belt repeated by folding or faulting. Probably these exposures prove that the Mettawee and Schodack lithologies are intertonguing facies, each here represented by two tongues. Ferruginous quartzites that have been called Eddy Hill and Zion Hill appear to be beds intercalated within Schodack facies, only locally useful as marker beds.

91.7 Stop 11. Contorted black slate and limestone. Typical Schodack lithology.

91.8 - 91.9 Top of hill. Black slate on left seems to outline trough of syncline. Last outcrops may be overturned.

92.5 Green slate, overturned?, on left. May be upper tongue of Mettawee facies.

92.8 - 92.9 Dolomite and dark banded slate on left. May be lower tongue of Schodack facies.

93.1 Dark banded slate on right.

93.5 Cross Poultney River into Vermont (town of Fair Haven). Green slate in river just to left.

95.1 South end of village of Fair Haven. Very sharp turn to right onto Route 22A, up steep hill to grade crossing.

95.2 Green slate (Mettawee?) in left gutter; ridge to left is grit and quartzite (Bomoseen?).

95.7 Small slate quarry to left (Mettawee).

96.6 - 97.0 Bluffs of green and purple Mettawee slate on left.

97.0 Bear right across Poultney River into New York, following Route 22A.

97.9 Dark slate on right.

98.4 Limestone conglomerate on right. These rocks are presumably Schodack formation, and Dale (1899) reports Cambrian fossils at two places along this road.

98.8 Dark slate on right; ferruginous sandstone at end of outcrop.

99.1 - 99.2 Ferruginous sandstone on right. Enter Castleton quadrangle.

99.6 Stop 12. At road forks. See Larrabee, 1939, p. 47; Fowler, 1950, p. 54. Rocks at forks are ferruginous sandstone, "Zion Hill quartzite", with some black slate at north end of cut. On up right fork are outcrops of limestone conglomerate (followed on hill above by another band of ferruginous sandstone); finally dark greenish and bluish banded slate, probably Deepkill (Lower Ordovician). Structural evidence indicates Ordovician is overturned and probably whole sequence is. Limestone conglomerate with upper ferruginous sandstone may belong to Schodack formation, but it may also belong to Deepkill formation

(Normanskill formation is well exposed on opposite (upright) limb of syncline, from 1 to 2 miles farther on along Route 22A (right fork at forks). Red slate is especially well shown about 2 miles on, and also in red slate quarry to left of main road. Cars proceeding this way can make sharp left turn about 2.2 miles on, rejoining itinerary in village of Poultney at mileage 101.1.)

Proceed along left fork into village of Hampton.

100.0 Turn left across bridge into Vermont (town of Poultney).

100.8 - 100.9 Village of Poultney; take second left turn across railroad tracks.

101.1 Intersection with Route 30. Continue east on road marked East Poultney toward Middletown Springs, Tinmouth, and Wallingford.

102.6 East Poultney.

105.4 In stream to right. Nassau formation; green phyllite and grit.

105.6 Leaving Castleton quadrangle, entering Pawlet quadrangle.

106.0 Town line. Leaving Poultney, entering Middletown.

109.9 Middletown Springs. Join Route 3; go east (straight ahead).

112.2 Stop 13. Town line. Leaving Middletown, entering Tinmouth. On hill to north is exposure of east margin (?) of Taconic overthrust sheet. Nassau (?) and Hortonville formations. Thrust plane apparently folded.

112.3 Leave Route 3, bearing right toward Tinmouth.

115.7 Turn left at Tinmouth village.

117.0 Turn left (north).

117.1 Turn right (east).

117.6 Cheshire quartzite on ridge to right. This Cheshire is on west flank of Clark Mountain anticline.

117.9 Height of land on Clark Mountain. Cheshire quartzite to north and south of road. View west into Tinmouth valley and Taconic Range beyond.

118.1 Moosalamoo phyllite on west limb of Clark Mountain anticline. View east across Vermont Valley to Green Mountains.

118.6 Turn sharp left. Road follows town line between Tinmouth and Wallingford for next 0.4 mile. Excellent view toward the east.

119.0 Leave town line to enter Wallingford township.

119.3 Leave Pawlet quadrangle to enter Wallingford quadrangle.

119.4 - 120.1 To right of road. Hortonville slate. This rests on Whipple limestone, which in turn here rests unconformably on Pre-Cambrian.

121.0 Cross Otter Creek. Monkton formation in stream.

121.1 Traffic light at cross roads in Wallingford. Turn right (south) on Route 7.

122.2 - 122.4 To right of road. Mallett facies of Dunham dolomite; also Monkton formation. Highly folded.

122.8 To right of road. Dunham dolomite.

123.0 Hill 1/2 mile to east (Green Hill) is doubly plunging anticline of Cheshire quartzite.

123.6 Stop 14. Highway cut and hill to west of road. Monkton, Winooski, Danby, and Boardman formations on the west flank of the Green Mountain anticlinorium.

125.0 To right of road. Upper calcitic marble of the Boardman formation.

125.2 Quarry to right of road. Upper calcitic marble of Boardman formation; to left of road (east) is intermediate dolomite of the Boardman formation.

125.7 South Wallingford.

125.8 Quarry to right of road in Boardman formation. Danby formation in stream on left.

125.9 - 126.0 Boardman formation.

126.5 Stop 15. Side road goes off to right. Outcrops on hill to west of highway. Volcanics in Ordovician. Most easterly outcrops belong to Boardman formation; progressively younger rocks to west are volcanics (light-colored gneiss and amphibolite), Whipple marble, a five-foot bed of volcanics, and Hortonville slate. The Whipple includes deformed limestone conglomerates.

Return north on Route 7 to Wallingford.

131.9 Turn right at traffic light in Wallingford, going east on Route 103A.

134.0 View of White Rocks (Cheshire quartzite) on Green Mountain front 1 1/2 miles to southeast.

134.1 Leave Route 103A, taking right turn toward White Rocks Picnic Area.

134.2 Turn sharp right at road junction.

134.7 White Rocks Picnic Area. Park. Contact of Mendon series and Mount Holly gneiss is 1/8 mile east of here but will not be visited. Take Cliffside trail to lookout; about 1/4 mile distant, 200 foot climb. Cheshire quartzite. View of Green Mountain front, especially White Rocks. View to west. Three miles to west is Clark Mountain, an anticline in which Pre-Cambrian rocks are brought up. Still further west are the Taconics. Through a gap one can see the Adirondack Mountains.

Return to Wallingford.

137.4 Traffic light in Wallingford. Turn north on Route 7.

139.1 Town line. Leaving Wallingford, entering Clarendon.

139.5 Leaving Wallingford quadrangle, entering Rutland quadrangle.

140.6 Cross Mill River.

143.1 Junction with Route 103. End of itinerary.

Itinerary

Central and Eastern Vermont

Mileage

0.0 Junction of routes 7 and 103 5 miles south of Rutland. Travel southeast on route 103 for next 30 miles. Start in Rutland quadrangle.

1.5 East Clarendon.

2.0 Town line. Leaving Clarendon, entering Shrewsbury. Leaving the Vermont Valley and entering the Green Mountains.

2.8 Stop 1. Large road cut north of road. Gneiss of Mount Holly series.

4.9 Leaving Rutland quadrangle, entering Wallingford quadrangle.

6.4 Cuttingsville. For next half mile the route crosses the poorly exposed edge of an alkalic stock of the White Mountain magma series. Chiefly syenite, but has some quartz syenite, essexite, and nephelite-sodalite syenite.

6.7 Town line. Leaving Shrewsbury, entering Wallingford.

8.9 East Wallingford.

9.3 Town line. Leaving Wallingford, entering Mount Holly.

9.7 To left of road. Mount Holly series; gneiss, folds, and thrust fault.

11.1 To left of road. Mount Holly series. Gneiss and amphibolite; folded.

11.3 Mount Holly Station. To left of road, amphibolite; 2 anticlines.

12.8 Height of land (Summit).

13.7 To left of road. Mount Holly series; gneiss. Ludlow Mountain to the southeast has fire tower.

15.6 Cross to north bank of Branch Brook.

16.1 Leaving Wallingford quadrangle, entering Ludlow quadrangle.

17.0 Highway crosses to north bank of Branch River. Town line. Leave Mount Holly, enter Ludlow.

17.1 Buttermilk Falls. Quartzite of Mount Holly series dips east.

17.2 Highway crosses to south bank of Branch River.

17.3 - 17.9 On right. Intermittent outcrops of schists of Mount Holly series.

18.1 In brook to left. Gneiss of Mount Holly series.

18.8 To right of road. Hoosac formation, albite schist.

18.9 Junction with route 100. Turn north (left) on route 100.

19.7 South end of Reservoir Pond.

20.2 South end of Rescue Lake.

21.9 Town line. Leaving Ludlow, entering Plymouth.

22.7 Tyson Village. South end of Echo Lake.

23.1 Trail up Dry Hill goes off to left. One half-mile to the northwest up the trail, and 500 feet above the highway, are excellent exposures of deformed conglomerates in base of Tyson formation.

23.8 South end of Lake Amherst.

24.1 Stop 2. Road cut to west of highway. Tyson formation. Conglomerate with deformed pebbles.

24.3 To left of road. Conglomerate with deformed pebbles.

25.0 Cross Black River, leave route 100, turning right on to dirt road.

25.1 To left of road. Hoosac formation, albite schist.

25.4 Trail goes east to quarry in dolomites of Plymouth member of the Hoosac formation.

25.8 Stop 3. 15-foot cliff to east of road. Hoosac formation, Plymouth member. Dolomite and quartzite. Also schists of upper part of the Hoosac formation. Return to intersection of routes 100 and 103.

32.7 Junction of routes 100 and 103. Go south on route 103 toward city of Ludlow.

33.1 To left of road. Schists of upper part of Hoosac formation.

33.5 To right of road. Schists of upper part of Hoosac formation.

33.8 To right of road. Schists of upper part of the Hoosac formation.

34.2 Leave route 103, turn right on to road to Ludlow Mtn. Fire Tower.

34.8 Stop 4. Dirt road south, over wooden bridge. Walk south about 200 yards to brook. Base of Tyson formation (schist, conglomerate, and grit) resting unconformably on Mount Holly gneiss; pegmatite in gneiss. Return to cars and head back down hill.

35.5 Turn right on to route 103.

35.9 Traffic light in Ludlow.

36.1 Cross Black River.

36.2 Leave route 103. Turn left (north) on to Commonwealth Avenue.

36.4 To right of road. Schists of Pinney Hollow formation.

36.8 To right of road. Schists of Pinney Hollow formation.

37.7 Stop 5. Outcrop in fields to west of road. Pinney Hollow formation. Schists and actinolitic greenstones.

37.9 To right of road. Ottauquechee formation; black phyllite.

38.1 To right of road. Ottauquechee formation.

38.4 To left of road. Ottauquechee formation. View of Mt. Ascutney to the east.

38.7 Four corners. Turn right.

39.3 Both sides of road. Schists of Moretown formation.

39.8 Stop 6. Outcrops along road and in fields to east. Moretown formation. Greenish quartzite with garnet.

40.9 To left of road. Moretown formation.

41.0 To left of road. Moretown formation.

41.3 Turn left (east) on to route 103.

41.6 Smithville. To left of road. Moretown formation; light-green quartzites and schists; folds.

41.7 500 feet to left of road. Large ledges of serpentine.

41.9 Town line. Leaving Ludlow, entering Cavendish.

42.4 Stop 7. Outcrops on north side of highway. Serpentine with talc-carbonate zone. Serpentine continues for 0.3 mile.

43.4 Proctorsville. Turn right, continuing on route 103 toward Chester.

44.1 On left side of road. Waits River formation in center of Proctorsville syncline.

44.6 Stop 8. Road cut on east side of highway. Waits River formation. Garnet-biotite schist; also brown-punky-weathering gray limestone. Beware of traffic! Entering Proctorsville Gulf.

Waits River formation continues for 0.2 mile. The Gulf then cuts across the east limb of the syncline, exposing the various formations in succession down to and including the Hoosac formation.

46.0 Leaving Proctorsville Gulf.

46.1 Town line. Leaving Cavendish, entering Chester. To right of road is Chester gneiss in the core of an inverted anticline that is a digitation of the Chester dome.

46.4 Road from right at B. M. 827.

46.8 Hoosac formation of east flank of the inverted anticline.

46.9 Pinney Hollow formation in center of inverted syncline.

47.1 Hoosac formation on the west flank of the Chester dome.

47.3 Road from left near B. M. 765.

47.4 To right of road. Hoosac formation.

47.5 Road cut on right. Hoosac formation. Gneiss, schist, and dolomitic marble with diopside-actinolite granulite.

47.6 Stop 9. Bridge over railroad and Williams River. East of bridge is abandoned quarry in schist of the Hoosac formation; garnet, staurolite, and kyanite. Outcrops continue for 0.2 mile to south along route 103.

47.9 To left of road. Chester gneiss of core of Chester dome.

48.3 Gassetts. Junction of routes 103 and 10. Stay on route 103.

48.8 - 49.2 To left of road. Chester gneiss.

49.5 To left of road. Amphibolite in Chester gneiss.

49.7 Stop 10. Road cut on east side of highway. Chester gneiss . Granulated biotite gneiss. Dips gently westward.

50.1 - 50.5 To left of road. Chester gneiss and amphibolite.

52.1 North Chester (stone houses).

52.4 To left of road. Chester gneiss.

52.5 Continue straight ahead where route 103 takes sharp turn right over Williams River.

53.3 Cross route 11 (Chester-Springfield road).

53.6 Chester gneiss on left.

54.0 To left of road. Chester gneiss.

54.2 Side road from left.

54.5 Chester gneiss.

54.7 To left of road. Chester gneiss. Leave Ludlow quadrangle, enter Saxtons River quadrangle.

54.9 - 55.1 Chester gneiss.

55.2 Road fork at B. M. 535. Bear left.

55.4 Stop 11. In fields north of road. Lower part of Hoosac formation. Gneiss, schist, and amphibolite; a few lime-silicate beds. Excellent reversed drag folds.

55.6 <u>Stop 12</u>. Outcrops in field north of road. Hoosac formation, augen gneiss member.

55.9 Town line. Leaving Chester, entering Springfield.

56.1 Town dump to right of road. To left of road, upper part of Hoosac formation; schistose biotite-muscovite gneiss.

56.2 <u>Stop 13</u>. Outcrops in field north of road. Town line. Leaving Springfield, entering Rockingham. Pinney Hollow formation. Garnet-muscovite-chlorite schist; epidote-amphibolite bands.

56.4 Moretown formation. Amphibolite. Folds.

56.5 Side road goes off to left. Moretown formation.

56.7 Road junction at B. M. 550. Continue south.

57.4 Cross Williams River

57.5 Turn left (south) on route 103.

58.2 Side road goes left.

58.7 To right of road. Cram Hill formation.

59.2 Crossing Shaw Mountain formation, not exposed here.

59.8 Leave route 103, turn left (north).

60.2 <u>Stop 14</u>. Brockway Mills. Waits River formation is exposed in bed of Williams River. Interbedded phyllite and brown-weathering gray limestone. Quartz-zoisite pods. Turn right (east) at north end of the bridge.

60.6 To left of road. Waits River formation.

60.9 To left of road. Standing Pond volcanics. Amphibolite and biotite gneiss.

61.1 Standing Pond volcanics. Amphibolite.

61.2 Standing Pond volcanics. Amphibolite with garnets 1/2 inch in diameter.

61.4 To left of road. Waits River formation.

61.5 Bear right at road fork.

62.1 - 62.3 Standing Pond volcanics. Garnetiferous amphibolite.

62.4 Side road goes off to right. Standing Pond formation.

62.5 Entering Bellows Falls quadrangle. (Geological map of this quadrangle has been extensively revised west of the Connecticut River.)

62.7 Town line. Leaving Rockingham, entering Springfield.

63.0 To right of road. Waits River formation.

63.1 To left of road. Waits River formation.

63.2 Stop 15. Cobble Hill. At road are exposures of Waits River formation. Exposures of Standing Pond volcanics begin 100 feet east of road and continue east for 1/4 mile. Most westerly exposures are amphibolite. Some beds of garnet amphibolite are found 500 feet east of the road. Amphibolite with feldspar fragments, apparently a crystal tuff. Most spectacular rock, a coarse schist with large sprays of hornblende up to 6 inches long and garnets several inches across are found about 1000 feet east of the road near top of hill. Also note reversed drag folds. Continue north.

63.5 Side road from left.

63.8 Entering Claremont quadrangle.

64.7 Road comes in from left.

64.9 B. M. 722. Bear right at fork.

65.0 To right of road. Gile Mtn. formation.

65.6 Hardscrabble Corner.

65.7 Cross brook, take road to left down the valley.

67.0 Road comes in from the right.

67.2 Turn right on to route 11. In Black River are outcrops of Gile Mountain formation; phyllite and quartzose phyllite.

67.5 - 67.7 Gile Mtn. formation on opposite bank of river. Gile Mtn. is in core of syncline east of Chester dome.

68.0 Dam. In river are outcrops of Gile Mtn. formation.

68.2 Highway crosses to north bank of Black River.

68.3 To left of road. Phyllite of Waits River formation. In core of inverted anticline.

68.4 To left of road. Waits River formation; limestone and phyllite.

68.6 Paddock. Fields north of road. Stop 16. Standing Pond volcanics. Low-grade greenstones. Highly folded.

69.0 Standing Pond volcanics; chlorite schists.

69.2 To left of road. Orfordville formation, black phyllites.

69.3 Junction with route 5. Bear left toward White River Junction.

69.5 To left of road. Orfordville formation. Thin-bedded phyllite and quartzose phyllite.

70.1 At north end of toll bridge turn sharp left to follow route 5.

70.6 To left of road. Orfordville formation. Phyllite.

70.9 To left of road. Orfordville formation. Phyllite.

71.2 Cliffs west of road. Conglomerate in Hardy Hill quartzite.

71.4 Stop 17. Road cut on west side of highway. At road fork. Quartz conglomerate in Hardy Hill quartzite. Continue north on route 5. Note cliffs of Hardy Hill quartzite in hills immediately east of Connecticut River.

72.1 To left of road. Hardy Hill quartzite; garnetiferous phyllite and pebbly quartzite. Cliffs to northwest of fossiliferous quartzite.

73.3 Stop 18. Road comes in from right. Road cut on west side of highway. Orfordville formation(?). Fossiliferous quartzite; brachiopods, crinoid columnals, corals. Paleontologists will not commit themselves further than to say these rocks are Ordovician, Silurian, or Devonian.

Return south on route 5.

77.3 Take left fork to continue south on route 5.

77.5 Bridge over Black River.

78.5 Entering Bellows Falls quadrangle. To right of road. Greenstones; either Standing Pond brought up in an anticline or a lens in the Orfordville formation.

79.6 Town line. Leaving Springfield, entering Rockingham. To right of road. Orfordville formation; black phyllite. Outcrops continue for 0.6 mile.

83.4 To right of road. Hardy Hill quartzite.

83.5 Orfordville formation; garnetiferous phyllite.

83.7 Falls Mountain ahead on left across Connecticut River is composed of schists of the Littleton formation.

84.2 Orfordville formation; Garnetiferous phyllite.

84.4 To right of road. Hardy Hill quartzite and conglomerate.

84.5 Bridge over Williams River.

84.7 Orfordville formation; phyllite.

85.1 Junction with route 103. Continue south on route 5. To right of road. Orfordville formation (dark phyllite) and conglomerate Hardy Hill quartzite.

85.4 To right of road. Orfordville formation; black phyllite.

86.9 To right of road. Orfordville formation; black phyllite.

87.1 Stop 19. Orfordville formation. Dark phyllite with thin gray micaceous quartzite. Note bedding and cleavage.

87.3 To right of road. Orfordville formation.

87.6 City limits of Bellows Falls. Crossing Northey Hill fault. To east of fault is Littleton formation. Stratigraphic throw approximately 10,000 feet.

88.0 Turn left at fork in road toward business district of Bellows Falls.

88.2 Do not cross Connecticut River on this bridge.

88.6 Windham Hotel. Turn left to get on to route 12.

88.7 Diversion canal for hydroelectric plant.

88.8 West end of bridge over Connecticut River. Boundary between New Hampshire and Vermont.

Itinerary

New Hampshire

Itinerary begins at the western end of the southern bridge over the Connecticut River at Bellows Falls. Do not confuse the water diversion canal for the hydro-electric plant in Vermont with the Connecticut River. The west end of the bridge is the border between Vermont and New Hampshire. For thirty miles, the trip follows Route 12 to and beyond Keene, New Hampshire.

Use geological map of Bellows Falls quadrangle by F. C. Kruger.

Mileage

0.0 Stop 1. West end of bridge over the Connecticut River. Parking is a big problem here. Do not try to park in New Hampshire, as the road is narrow. Park somewhere in Bellows Falls. Walk across the bridge, turn right on Route 12, walk an additional 1/8 mile to where the road is nearly at river level. Do not cut down the steep bank because it is covered with poison ivy. Go to outcrops in river.

Upper contact of Bellows Falls pluton. Bethlehem gneiss overlain by sillimanite schists of the Littleton formation. Contact strikes northwest, dips 30° NE. This is the best place on the trip to collect sillimanite schist from the Littleton formation; numerous blocks can be broken up. The cliffs of Falls Mountain, to the east, are composed of schists of the Littleton formation.

Return to cars and follow Route 12 south; route follows base of cliffs on Falls Mountain for one mile.

1.3 Cold River. Left of road is Littleton formation; garnetiferous mica schist with segregation bands of quartz and feldspar one inch thick. Dips 30° NE.

For next few miles the trip is on a river terrace without any exposures of bedrock.

4.6 Walpole

6.0 Left of road is Littleton formation, dips 15° E.

6.9 Brook, Littleton formation, flat.

8.0 Left of road, Littleton formation, mica schist, dips 10° N.

8.5 Railroad crossing.

9.1 Town line. Leaving Walpole, entering Westmoreland.

9.2 to 9.5 To left of road. Littleton formation, mica schist.

10.2 Junction of Routes 63 and 12. Bear left on Route 12. To left is binary granite of New Hampshire magma series, cut by quartz veins.

10.7 Entering Keene quadrangle. Use geological map of Keene and Brattleboro quadrangles by G. E. Moore. For the next five miles the highway has been relocated and differs from the map.

11.3 To left of road. Littleton formation, mica schist.

11.6 Stop 2. Beware of traffic! Partridge, Clough, and Littleton formations on the northwest flank of the Westmoreland-Swanzey dome.

In the large western cut are mica schists of the Littleton formation; these schists contain garnet and staurolite. There is one four-foot bed of actinolite-diopside granulite. Although there is much minor folding, the average dip is gentle to the northwest.

In the smaller eastern cut is exposure of Clough quartzite dipping 30° NW. This is also unusually well exposed in the gorge to the south.

Still further east the Partridge formation is exposed in the bed of Mill brook under the bridge.

12.1 Stop 3. Partridge formation. Folded mica schist.

12.6 To right of road. Partridge formation; mica schist with garnet and kyanite; quartz veins also contain kyanite.

12.9 Highway crosses to north (left) bank of Mill Brook. Partridge formation in bottom of stream bed poorly exposed.

East of here the route crosses over a band of Ammonoosuc volcanics, 1/2 mile wide, which is unexposed along the highway.

14.0 East Westmoreland.

14.5 Left of road, quartz monzonite of Oliverian magma series.

14.7 Wilbers. Stop 4. Oliverian magma series. Gray, granular biotite-quartz monzonite; large quartz grains 1/4 inch across. Gentle dip to west.

15.6 Town line. Leaving Westmoreland, entering Surry.

15.7 Both sides of road. Quartz monzonite of the Oliverian magma series. Dips gently west.

16.1 Bridge over railroad. Stop 5. From north end of bridge, walk 200 feet east along top of railroad cut. Normal fault dipping east; quartz monzonite of the Oliverian magma series to west of fault, Ammonoosuc volcanics to east. This is the western border fault of the Grays Hill graben, within which the roof-rocks of the Westmoreland-Swanzey pluton are preserved. Exposures in railroad cut are excellent, but it is dangerous for a large group to enter the cut.

Walk 300 feet east on highway to see exposures of Ammonoosuc volcanics on south side of highway. Epidote amphibolites, dipping 20° W.

Walk east along the highway. At 16.3 is town line; leaving Surry, entering Keene. One-quarter mile east of the highway bridge is the western end of a big cut in broken and partially silicified quartz monzonite of the Oliverian magma series. At the extreme eastern end of the exposures is a completely silicified rock on the eastern border fault of the graben.

Silicified zone is at 16.7 miles. View of Mt. Monadnock to the east.

17.2 To right of road. Quartz monzonite of the Oliverian magma series. Foliation dips gently, locally folded.

17.8 To right of road. Quartz monzonite of the Oliverian magma series.

20.4 Junction with Route 9 (to Brattleboro). Continue on Route 12.

22.0 Turn right in Keene, continuing on Route 12.

22.1 Keene railroad station.

22.4 Route 101 goes left; stay on Route 12.

24.0 Road to Swanzey goes right; stay on Route 12.

24.1 Town line. Leaving Keene, entering Swanzey.

24.4 Crossroads. Will return here later.

25.3 Race track on right. Entering Monadnock quadrangle. Use geological map by K. Fowler - Billings.

27.3 Road junction near B. M. 620; road to East Swanzey goes right.
To left of road is outcrop of Oliverian magma series, foliation dipping 45° E. Continue on Route 12.

27.4 To left of road. Clough quartzite on east flank of Westmoreland-Swanzey dome. Micaceous quartzite, locally feldspathic. Dips 60° to 80° E.

27.5 To left of road. Littleton formation, mica schist.

27.6 To left of road. Concord granite.

27.7 Town line. Leaving Swanzey, entering Marlboro.

28.1 Cross bridge to west side of the South Branch of the Ashuelot River.

28.2 To right of road. Littleton formation, mica schist.

28.3 Bridge over river.

29.0 Bridge over river; beginning of long exposures of the Littleton formation.

29.5 Bridge over river. Town line. Leaving Marlboro, entering Troy.

29.6 Stop 6. Large road cut typical of the lower part of the Littleton formation. Mica schist with small garnets, as well as small and inconspicuous needles of sillimanite. Local segregation bands, one inch thick, of quartz and feldspar. One zone of lime-silicate concretions; individual concretions up

to three feet in diameter; concretions contain diopside, lime-garnet, amphibole, and plagioclase.

Minor folds plunge steeply northeast. Pegmatite, some of which contains small beryls.

Return toward Keene on Route 12.

33.8 Race track on left. Re-enter Keene quadrangle.

34.8 Turn right at crossroads to head toward South Keene.

35.2 Town line. Leaving Swanzey, entering Keene.

35.5 Re-enter Monadnock quadrangle.

35.7 Turn right on Route 101 toward Marlboro. Belt of Ammonoosuc volcanics on east flank of the Westmoreland-Swanzey dome is not exposed here.

37.0 View of Mt. Monadnock.

37.2 Town line. Leaving Keene, entering Marlboro.

37.9 Marlboro.

38.2 Take Route 124, which goes straight ahead. Route 101 goes left.

39.1 Big gravel pit on the left.

39.6 Stop 7. Walk 1000 feet north on dirt road. Large abandoned quarry in the Concord granite. Flow-banding and excellent sheeting.

Continue southeast on Route 124.

40.5 Littleton formation, mica schist.

40.6 Littleton formation, mica schist.

41.8 Stop 8. Spaulding quartz diorite. Some pegmatite.

43.5 Littleton formation, mica schist.

44.3 Town line. Leaving Marlboro, entering Troy.

44.6 Stop 9. Perkins Pond. Town line; leaving Troy, entering Jaffrey. View of Mt. Monadnock.

45.5 To right of road. Spaulding quartz diorite.

45.6 Stop 10. Littleton formation. Sillimanite-garnet schist with a little black tourmaline. Sillimanite up to one inch long. Dips northwest. Additional outcrops for 0.2 mile to east.

46.2 Stop 11. Foot of road to Halfway House on Mt. Monadnock. Walk one-half mile up the road toward the Halfway House. Exposures of rusty quartzite member of the Littleton formation, including a few lime-silicate beds. 0.4 mile up the road are the overlying mica schists of the Littleton formation.

After returning to the cars, continue southeast on Route 124.

47.1 Road to Fitzwilliam. Spaulding quartz diorite on the left.

Continue on Route 124.

47.3 To left of road. Spaulding quartz diorite.

47.5 To left of road. Spaulding quartz diorite.

47.7 Crossing a second belt of the rusty quartzite; obscure exposure in a driveway on right.

48.0 To right of road. Spaulding quartz diorite.

48.4 to 48.8 Littleton formation on the left.

49.8 Monadnock Inn in Jaffrey.

51.5 East Jaffrey. Just before crossing the Contoocook River turn left on to Route 137.

53.1 To right of road. Kinsman quartz monzonite.

53.2 Stop 12. Kinsman quartz monzonite.

53.9 To right of road. Littleton formation, rusty schists.

55.0 Route 137 bears left at B. M. 1070.

55.6 Town line. Leaving Jaffrey, entering Dublin.

57.0 Cross roads, continue on Route 137.

58.4 Bonds Corner. Leave Route 137, turning right on Route 101.

58.6 Large boulders of Kinsman quartz monzonite.

60.0 Leaving Monadnock quadrangle to enter Peterboro quadrangle, for which geological quadrange map is not available.

60.1 To right of road. Littleton formation, mica schist.

60.5 Town line. Leaving Dublin, entering Peterboro.

61.2 To right of road. Kinsman quartz monzonite.

61.4 West Peterboro.

63.3 Peterboro. Muscovite granite forms falls of Nubanusit Brook to right of highway. Difficult to see from road.

63.5 Center of Peterboro.

63.6 After crossing bridge, turn right on Route 101.

67.0 View of Pack Monadnock Mountain to the northeast.

67.1 To left of road. Littleton formation, rusty schists.

68.0 Stop 13. Road to top of South Pack Monadnock Mountain (General Miller Park). Outcrop on left side of road. Littleton formation. Rusty schist, micaceous quartzite, and lime-silicate bed. Gentle dip. Pegmatite. An excellent section is exposed on the road up the mountain.

68.3 View east across the seaboard lowland.

69.2 Road cut. Concord granite.

73.0 West Wilton.

73.8 Continue on Route 101 to Wilton.

74.7 Wilton Center.

75.4 Littleton formation; mica schist. Also pegmatite.

76.2 Entering Milford quadrangle, for which geological quadrangle map is not available.

76.8 Railroad crossing.

76.9 Just before center of Wilton turn left on Route 31 toward Greenfield.

77.4 Stop 14. Littleton formation. Somewhat rusty coarse muscovite-biotite-quartz schist; also gneiss. Dip north and northwest. Return southeastward to Wilton.

77.9 Junction with Route 101. Continue southeast on Route 101 toward Milford.

78.4 Wilton.

79.0 Bridge. Schists of Littleton formation in river bank to north.

82.9 Milford. Turn right (south) on to Route 13. Traveling south you will see abandoned quarries in the Milford granite (same as the Concord granite).

84.5 On right. Abandoned quarry in Milford granite, now full of water. There are excellent exposures in the quarries east and west of here.

84.7 Stop 15. Belt on map labelled "Granite, quartz monzonite, and granodiorite". This is one phase of the Fitchburg granite of Massachusetts, which Emerson divided into two types:
(1) a "central" type, similar to the Concord granite;
(2) a "marginal" type such as you see in this exposure.
Here the rock is a pink foliated gneiss; note folded pegmatite. In places in this belt the rocks are much more granitic looking, elsewhere they are obviously metasediments.
Return to Milford on Route 13.

86.5 Turn right on Route 101A, toward Nashua.

88.6 Town line. Leaving Milford, entering Amherst.

88.7 On right side of road. Abandoned quarry in a fine-grained phase of the Concord granite; cuts gneiss similar to that seen at stop 15.

89.2 Ponemah. Turn right on Route 122 toward Hollis.

90.5 Town Line. Leaving Amherst, entering Hollis.

92.6 Stop 16. Mica schist lentil in the Merrimack group. Spangled muscovite schist with some sillimanite; also gray biotite-quartz feldspar schist. Pegmatite.

Within the next two miles the grade of metamorphism drops from sillimanite zone to chlorite zone.

93.5 Stop 17. Merrimack group. White quartz-mica schist, purplish-brown biotite-quartz schist, and actinolite granulite.

94.5 Leave Milford quadrangle, enter Pepperell quadrangle.

95.0 Cross Route 130. One-half mile to the west is a road cut in phyllite typical of the chlorite zone. Village of Hollis 1/4 mile to left.

95.1 To right of road. Merrimack group. Brown-weathering siltstone, a few beds of phyllite.

95.7 Stop 18. Merrimack group, chlorite zone. Brown-weathering gray platy siltstone and gray siltstone with thin veneer of calcite on joint planes.

96.9 To right of road. Merrimack group.

97.6 To left of road. Merrimack group.

97.7 Massachusetts border.

Take Route 122 to Route 119. Turn left on Route 119 and follow to Littleton Common, where you pick up Route 2 to Boston.

Field Trip No. 2

OUTSTANDING PEGMATITES OF MAINE AND NEW HAMPSHIRE

Leader: Caleb Wroe Wolfe,
Boston University

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OUTSTANDING PEGMATITES OF MAINE AND NEW HAMPSHIRE

By Caleb Wroe Wolfe

Introduction

The pegmatites of New England, such as those of Paris, Maine, and Haddam Neck, Connecticut, have been famous in geologic literature because of their many pockets containing tourmalines of gem quality. Pegmatites, such as the Palermo Mine, North Groton, New Hampshire, with its rare phosphates, the Fisher Mine, Topsham, Maine, with its interesting pockets of topaz, and the Ruggles Mine, Grafton, New Hampshire, with its unusual aggregation of radioactive minerals, are famous for the unique mineral paragenesis to be found at each locality.

Many of these pegmatite localities are now dead from the view points of quarrying operations and mineral collecting. Others which are now active may be closed by the time of the field trip in November of 1952. For this reason the precise plans for the trip will remain rather fluid, leaving the opportunity for visiting choicer localities if they should appear during the summer of 1952. Due to limited time no stops will be made en route to Keene, New Hampshire, except for a brief stop near Troy, New Hampshire, for a view of classic Mt. Monadnock.

The accompanying outline map of New Hampshire shows the two principal pegmatite areas which will be visited, the Keene District and the Grafton District. The two principal active quarries in this district at the present time are the Colony Mine in Alstead, operated by the Golding-Keene Company, and the Ruggles Mine in Grafton, operated by the Whitehall Company. It is fairly certain that these two quarries will be in operation at the time of the field trips, and the two companies have graciously permitted examination of the properties. A large feldspar flotation plant has been erected by the Golding-Keene Company at Alstead near the town of Gilsum, New Hampshire. It is hoped that this plant will be in operation and open for an hour's inspection at the time of this trip.

The precise plans for the examination of New Hampshire pegmatites is as follows. The Old Colongy Mine will be visited; and, if there is time, two other interesting deposits will be visited, the Kidder Dike near the flotation plant and the Big Mine about 0.8 mile from the plant toward Gilsum. The latter two mines are not in operation at present but are of considerable interest. Any member of the excursion who does not wish to visit the flotation plant can spend more time at these two localities while the other excursionists examine the feldspar processing.

The Wednesday trip will involve visiting several localities in the vicinity of Paris, Maine. The exact plans for these visits will depend largely on the recency of quarrying activity. Mr. Stanley Perham of Trap Corner, Maine, plans to present a novel situation for the members of the excursion. A blast is to be set off just prior to the arrival of the party, in a section where pockets are know to exist in one of the better known pegmatite localities. The excursion members may thus have an opportunity to investigate the mineralogy of a newly opened pocket.

Geology

Location of area. The interesting pegmatites of New England, east of the Connecticut Valley, are restricted to two belts, Figure 1. The western pegmatites are located in the region just east of the Triassic fault block of the Connecticut

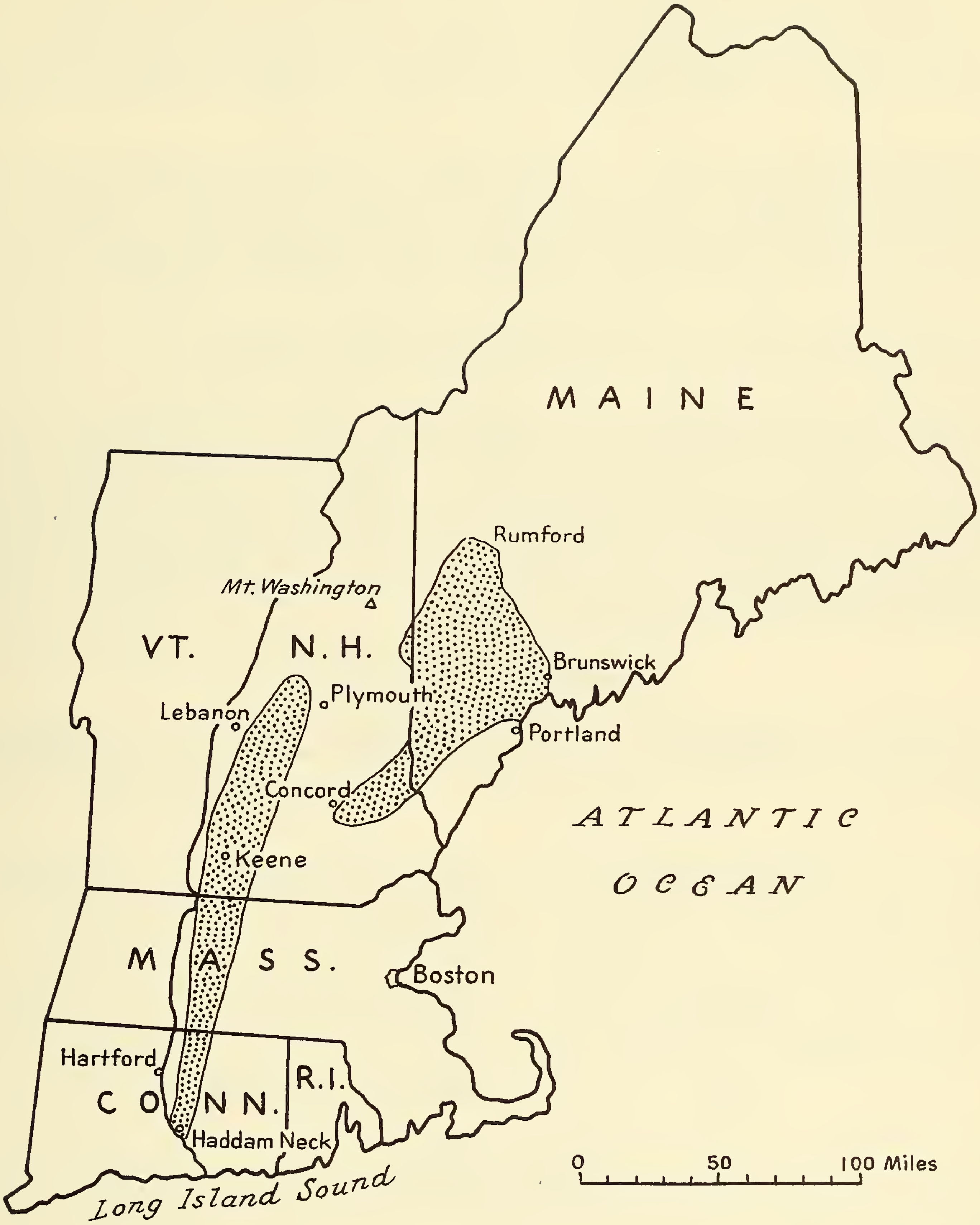


Figure 1. Index map of regions where pegmatites are extensively developed east of the Connecticut Valley in New England. Pegmatite areas are stippled.

Valley. A short distance south of Hartford, Connecticut, the Connecticut River leaves the Triassic basin and cuts through the pegmatite-bearing rocks of South Glastonbury, Portland, and Haddam Neck. Interesting pegmatites are to be found west of the Triassic basin, but they will not be included in this discussion. The region between Glastonbury and Keene is replete with pegmatites, but they are of little interest mineralogically, being monotonous repetitions of feldspar, quartz, and muscovite. The area from Keene north through Grafton, North Groton, and Rumney, New Hampshire, shows an amazing predominance of pegmatite concentration. The entire western belt gradually disappears as the main White Mountain mass is approached.

The eastern pegmatite belt is less linear in form than the western. The southwestern extension begins north and northeast of Manchester, New Hampshire, and extends northeasterly into Maine, forming a roughly triangular area with Brunswick, Maine, in the northeast corner and Rumford, Maine, in the northwest corner, It will be noted from Figure 1 that the northwesterly boundary of this area is rather irregular where a considerable area of carboniferous (?) volcanic rock outcrops in the Brownfield, Maine, region east of the Maine-New Hampshire boundary.

Lithology and stratigraphy. The pegmatites of New England are pre, syn and slightly post-tectonic intrusions associated with paleozoic geosynclinal sediments. The stratigraphy of the New Hampshire pegmatite region has been thoroughly described by Marland P. Billings and his coworkers in a series of quadrangle descriptions. The generalized stratigraphic column from their work is given on the following page. Billings (1946) recognizes four distinct magma series in New Hampshire. The oldest, the Highlandcroft series, and the youngest, the White Mountain Magma series, are of no importance as sources of pegmatitic fluids.

NEW HAMPSHIRE STRATIGRAPHY

Age	Formation	Lithology	Thickness
Quaternary			
Devonian Lower	Littleton	Slate, ss, schist volcanics	6,000'±
Silurian Middle	Fitch	Limestone, marble varied	550'±
Middle or Lower	Clough	Conglomerate, quartzite	150'±
- - - - - - - -	- - - - - - UNCONFORMITY	- - - - - - - -	- - - - - -
Ordovician Upper??	Partridge	Black slate, mica schist, varied	1,500'±
	Ammonoosuc	Volcanics, varied	2,000'±
	Albee	Quartzite, mica schist, varied	4,000'±
Middle??	Orfordville	Slate, graphite schist varied	4,000'±
	Waits River	Mica-quartz schist, calcareous	2,000'±
			20,000'±

The Oliverian Magma series seems to be an important source of pegmatites; and, as all workers have noted, occurs consistently at one horizon, near the top of the Ordovician (?) Ammonoosuc Volcanics formation. The usual structural form for the rocks of this magma series is that of a dome. Radially outward dips in the well-developed foliation result from the alignment of the plentiful biotite. Foliation in the center of the domes is less notable and is approximately horizontal. Since foliation is most pronounced near the contacts, the absence of foliation near the exposed central surface region can probably be attributed to the greater penetration of weathering and erosion in that area.

Two general hypotheses concerning the origin of these domes and of the Oliverian Magma series have been suggested. Chapman and others (1944) have suggested that the magma was uniformly intruded at the top of the Ammonoosuc formation in a series of broad sills of domal proportions. Kruger and Linehan (1941) have presented evidence for the floored character of these intrusives.

An exposure along the north cliffs of Miller's River just west of Erving, Massachusetts, presents an unusually sharp picture of the bottom of one of these domes and suggests a second explanation for their origin, Figure 2. In this outcrop the Albee formation may be seen in the fields sloping away from the cliffs toward the river. Typical Ammonoosuc rocks outcrop above these at the base of the cliff. The cliffs rise for about three hundred feet and with this rise there is a gradual but marked change in appearance of the Ammonoosuc rocks. At the bottom the rocks are massive without pronounced foliation. These are overlain by alternating dark and light layers simulating the so-called lit par lit injection. Gradually the concentration in dark minerals decreases until only a marked foliation remains without definite layers of dark minerals. Finally, even the foliation disappears, and an almost massive light-colored granitoid rock caps the cliffs.

Some distance away from the cliffs pegmatites become more and more predominant until the granitoid rock almost completely disappears. The coarsest pegmatites lie just below the contact with the Silurian Clough formation which is, in this case, a massive white quartzite.

This structural and petrologic picture, coupled with the fact that the Oliverian domes are universally found near the top of the Ammonoosuc formation and near the bottom of the Clough formation have led to the theory that the Oliverian magmas are derived by partial solution and liquefaction of rhyolitic (?) volcanic members of the Ammonoosuc formation. Whether this granitization approach or that of intrusion of magma from a deeper source be accepted, it is uniformly recognized that the magma was emplaced in pretectonic time just prior to and partially contemporaneous with the regional metamorphism, first described by Billings (1937).

The pegmatites which are derived from this magma series are uniquely devoid of mineralogical interest. Quartz, feldspar, and muscovite mica with occasional schorl occur in ever repeated monotony. Individual pegmatite masses of this category may show dimensions as large as 1500 feet in length, 200 feet in width, and indefinite depth. Many of them worked for their feldspar or mica content, but in others the quality and quantity are too uncertain for successful operation.

The New Hampshire magma series has yielded many important pegmatite masses of Western New Hampshire and presumably those of the Maine belt as well. No properly dated stratigraphic column for the country rocks of the Maine area has been developed, although the author and his students have demonstrated to their own satisfaction that the early and middle paleozoic stratigraphy of New Hampshire continues into the Maine region around Rumford. There is reason to believe that the New Hampshire magma series is intimately connected with the principal pegmatites of Connecticut, Massa-

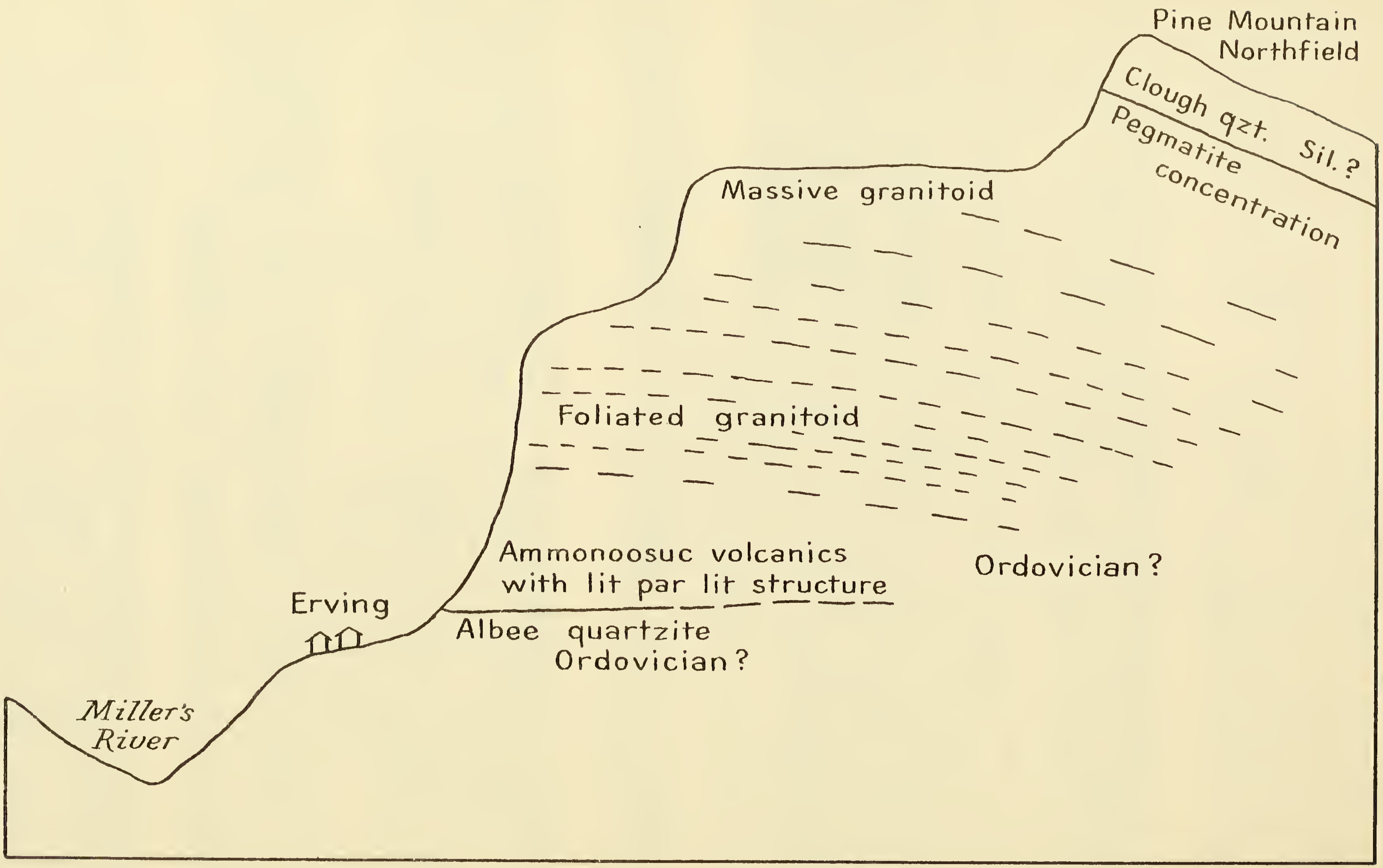


Figure 2. Generalized cross section of the Oliverian dome in the vicinity of Erving and Northfield, Mass.

chusetts, New Hampshire, and Maine.

Structurally, the New Hampshire magma series is syntectonic or slightly post tectonic. The youngest metasedimentary rocks which were intruded by these magmas were those of the Devonian Littleton formation. These rocks are also the youngest involved in the extensive orogeny which fashioned the present rock structures of the region. Billings et al have thus proposed that the orogeny is late Devonian or early Carboniferous. Age determinations of two New England pegmatites by use of lead-uranium determinations bears out the Devonian designation. The following table has been excerpted from a longer one given by Shaub (1938).

Age Determinations for Some New England Pegmatites
by Means of Lead-Uranium and Lead-Thorium Ratios.

Locality	Minerals analyzed	Age in Millions of years	
		Logarithmic formula	Corrected for AC-U
Rock Landing East Haddam, Conn.	Uraninite	297	269
Glastonbury, Conn. (Spinelli Quarry)	Samarskite	291	280
Portland, Conn. (Hale Quarry)	Monazite	276	266
Do	Uraninite	291	280
Strickland Quarry	Uraninite	304	293
Fitchburg, Mass.	Uraninite	370	356
Topsham, Maine	Samarskite	232	224
Grafton Center, N.H. (Ruggles pegmatite, pit at top of Mt.)	Uraninite	304	293

Chapman (1941) in his paper on "The Tectonic Significance of Some Pegmatites in New Hampshire" stresses the relationship of many pegmatites to the Bethlehem gneiss intrusion of the New Hampshire magma series. Although pegmatites are undoubtedly frequently associated with the Bethlehem gneiss in the form of thin narrow dikes and thin pods and lenses, it is as reasonable to suppose that the pegmatites and the gneiss are both genetically related to the same source of magmatic origin as that the pegmatites are segregations of residual fluids from the Bethlehem gneiss. In general the pegmatites which occur as dikes in the Bethlehem gneiss contain nothing more than schorl in addition to the usual feldspar, quartz,

and biotite or, more commonly, muscovite. Occasionally beryl occurs in these pegmatites when they are near the roof of a Bethlehem mass, as at Fitchburg, Mass., (Hitchen, 1935).

There is a marked mineralogic difference between the Keene pegmatites and the Connecticut and Maine pegmatites. This difference may be more apparent than real, but at present there seems to be a marked lack of lithium minerals and rare minerals in the Keene area. The Keene feldspar bodies, however, are remarkable in size and purity. An increasing mineralization of the pegmatites may be noted to the north of the Keene area, particularly in the Ruggles Mine in Grafton and in the Palermo Mine in North Groton. The unusual development of lepidolite and colored tourmaline which marks the Connecticut and the Paris, Maine, pegmatites is notably lacking in the Keen-Grafton districts.

One possible explanation for the variation in mineralization is, of course, that the pegmatitic magmas differed in the various regions. Another explanation might be that erosion has penetrated to different levels of pegmatite emplacement, the thought being that the lepidolite-tourmaline pegmatites formed at higher levels which have been completely stripped by erosion in the Keene-Grafton area. This theory would suggest that the absence of thick or of mineralized pegmatites in Massachusetts along the eastern flank of the Connecticut Valley is due to an even deeper penetration of erosion. In Maine, also, pegmatites markedly decrease in abundance, in size and in quality to the northeast of Rumford, possibly for the same reason.

Structure of the country rock. The paleozoic rocks which constitute the country rock of the pegmatites are exceedingly contorted in minor detail; but where the structures have not been obliterated by igneous intrusions they are remarkably simple in general structure. The major folds, as in the Littleton-Moosilauke area as mapped by Billings (1937) are rather broad and open anticlines and synclines modified by very complex minor folds. Steep angle reverse faults have been noted. In general the reverse or normal character of the faulting is obscure, but the fault zones are often marked by rather extensive silicified zones. The mineralization in and adjacent to these zones is almost non-existent. In the region of Surry, New Hampshire, some exceptionally fine reniform hematite and goethite has formed in a large quartz ridge which is presumed by Moore to have resulted from silicification along a fault. Figure 3 shows the relationships of the Oliverian domes to the pegmatites in the Alstead area.

Form and structures of the pegmatites. The forms of the pegmatites are almost limitless. They are concordant and discordant. They take the form of sills, laccoliths, phacoliths, lenses, pods, or dikes. The same pegmatite may be concordant in one section and discordant in another. The dimensions are variable from small pod-like segregations a few inches in diameter to bodies of unknown size. In the few cases where mining operations have proceeded to the bottom of a particular pegmatite, no sign of any feeder pipe or fissure has been observed.

Concerning the size and shape of New Hampshire pegmatites Olson (1950) states: "The known pegmatites of New Hampshire are as much as 400 feet thick and nearly 2 miles long; most are less than 50 feet thick and less than a few hundred feet long. In shape they range from thin sills of wide lateral extent to bodies that are almost circular in plan. Contacts between pegmatites and wall rocks are commonly irregular, and the bodies may be either concordant or discordant with the foliation of the country rock. The great majority cut across the foliation of the wall rocks, and even those bodies that appear broadly concordant generally transect the foliation in places. About three fourths of the pegmatites thus far studied in New Hampshire strike northeast, and most of the bodies dip at angles greater than 45°.

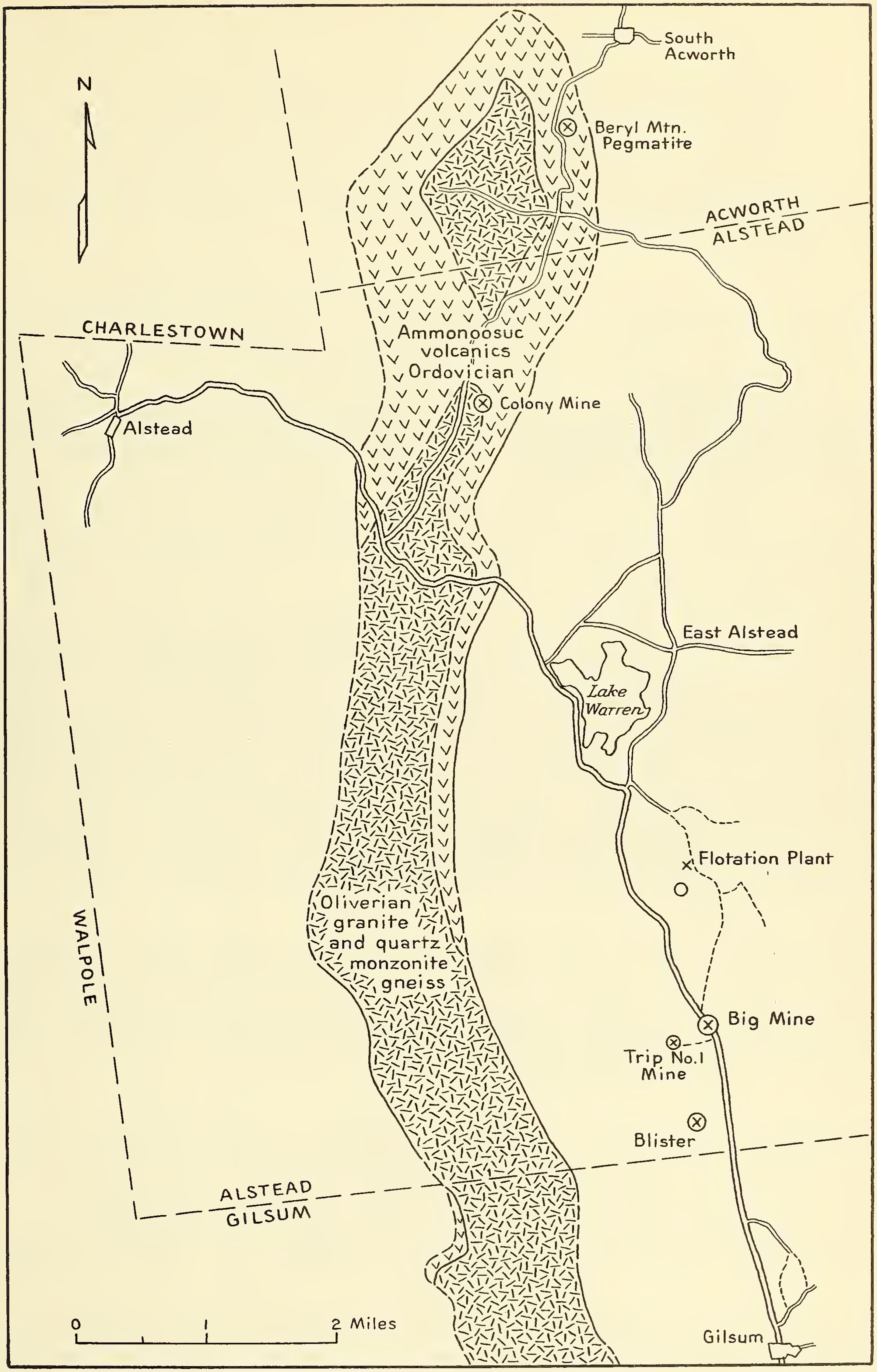


Figure 3. Pegmatites of Keene area in geologic setting. Unshaded region is mostly Devonian Littleton schist.

"Pegmatites mined underground or otherwise explored in three dimensions are commonly found to be lenticular or of varying thickness in both section and plan. Pegmatites in New Hampshire have been mined to relatively shallow depths; the deepest workings in the Big mine are about 285 feet deep. The Mud mine is about 170 feet in maximum depth. The Palermo incline is reported to extend to a vertical depth of 150 feet below the level of the main entrance to the underground workings. The greatest depth of workings at the Ruggles is about 140 feet, and at the French and Colony 130 feet. Most pegmatites vary in thickness and mineral content at depth, and such variations probably account for the abandoning of more mines than do operational difficulties due to depth. For example the pegmatite of the United Mine, 20 feet thick at the surface, diminished to only 18 inches in a distance of 90 feet down the incline."

Olson goes on to state that "The minerals of minable pegmatites are rarely distributed evenly throughout the pegmatite body, but are more or less segregated into different units of contrasting mineralogical composition and texture. The disposition of the various units within a pegmatite body generally follows a systematic scheme, common to many pegmatites in a given area or province, shown by a characteristic succession of zones from the walls of the pegmatite body inward to the core. It has been found desirable to adopt special terms for use in describing the internal structure of the pegmatite bodies. The general term pegmatite unit is applied to all divisions of pegmatites distinquishable by mineralogical or textural differences, regardless of their position within the pegmatite body. Zone is a more specific term, applied to systematically arranged units occurring as successive irregular shells from the walls inward.

"The fine-grained pegmatite, in units generally from less than an inch to 4 inches thick, in contact with the wall rock in many New Hampshire pegmatites, is referred to as the border zone. The outermost coarse-grained unit, next inside the border zone, is referred to as the wall zone, a name that has been in common usage in pegmatite mining because of the economic importance of the coarse muscovite in some wall zones. The innermost unit of the pegmatite body is appropriately called the core. The cores of New Hampshire pegmatites are typically either massive quartz or quartz-perthite mixtures. The zone or zones between the core and the wall zone are referred to as intermediate zones, and it has been found convenient to designate the innermost intermediate zone the core-margin zone. Pegmatite units that are not systematically arranged may be given appropriate names such as 'fracture fillings,' 'replacement units,' or 'pods'.

"The zonal structure of the pegmatites in New Hampshire rarely approaches the ideal form. The various units are commonly irregular in shape, and the textural or mineralogic changes commonly occur over a space of several inches or feet, therefore most boundaries between units are gradational. Furthermore, some units or zones are discontinuous, occupying a systematic position in parts of the pegmatite but absent from others." (Figure 4)

In Figure 4 Olson notes that quartz is most concentrated in the core; perthite is most concentrated in the core and core margin zone, is scarce in the intermediate zone, and is almost absent in the wall and border zones; graphic granite is abundant only in the intermediate and the core margin zones; plagioclase is in moderate abundance in the core margin zone and in great abundance in the two outer zones. The zonal distribution of muscovite is comparable to that of plagioclase; biotite, where it occurs, is principally in the core margin and intermediate zones.

In general, this tendency toward zoning is more pronounced in the Keene-Grafton pegmatites than in the rare mineral pegmatites of Maine. Secondary and even tertiary replacement of what may have been zoned pegmatites has so modified the usual zoning

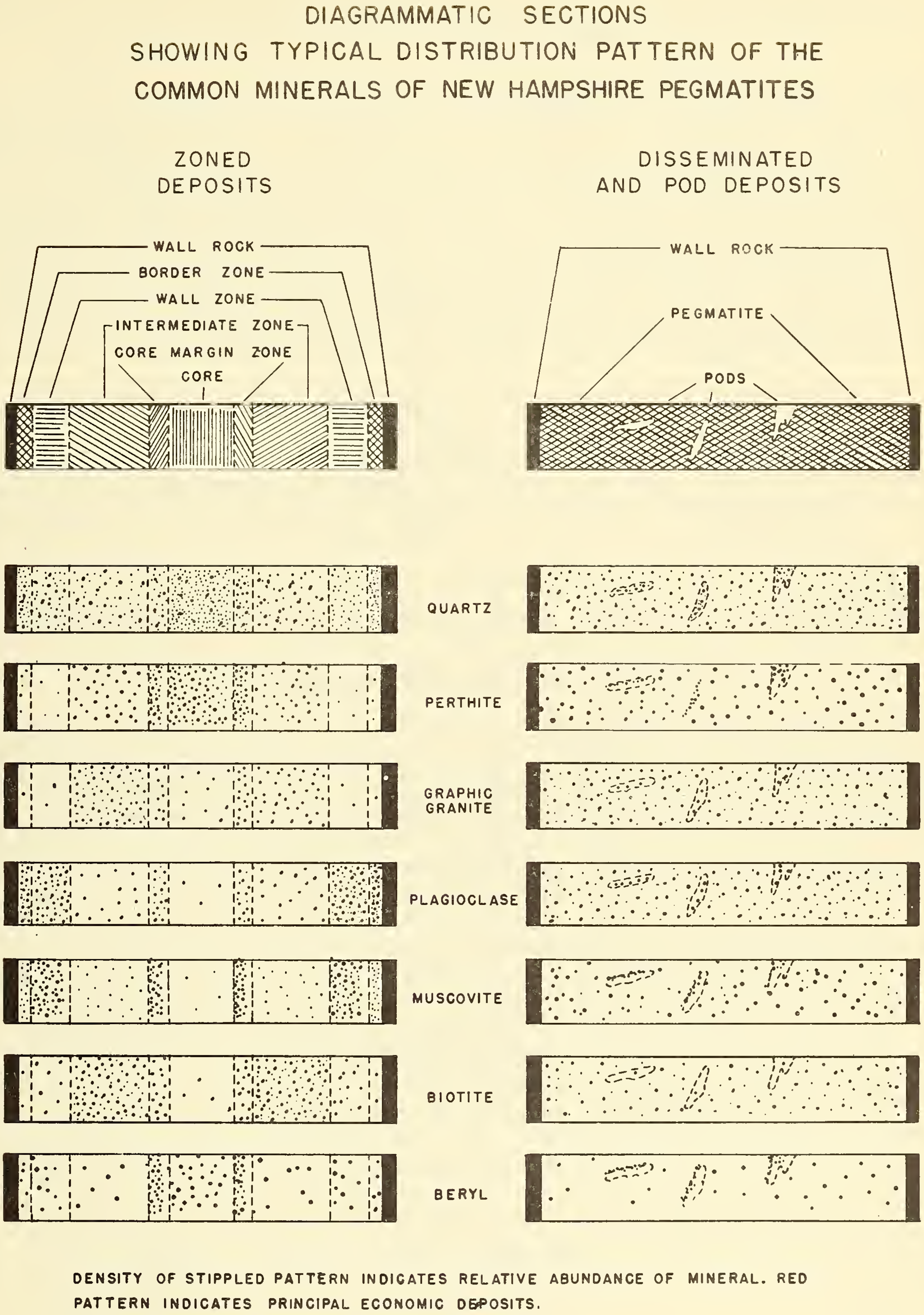


Fig. 4

Figure 4. Diagrammatic sections showing typical distribution pattern of the common minerals of New Hampshire pegmatites. After Olson

as to destroy it in many cases. It should be pointed out, also, that the concept of zoning in pegmatites must frequently be stretched beyond recognition when applied to even those pegmatites which have not undergone extensive alteration by later solutions. The tendency toward zoning is sufficiently marked, however, as in the case of the Palermo Mine, to convince even the skeptics of its occasional validity.

Chapman (1941) noted that pegmatites in the Bethlehem gneiss "are of three types-(1) segregation pegmatites, (2) shear zone pegmatites, and (3) filled fissure pegmatites. These pegmatites are of very little interest mineralogically or economically." In the Roll Stone Quarry of Fitchburg, Massachusetts, there are many of the filled fissure pegmatite dikes. Toward the roof of this intrusion, sheet pegmatites containing beryl, black tourmaline, and other minerals were extensive. Spodumene-bearing units associated with the granite, however, are formed only in intrusives in the bordering schists. In fact, the regional distribution of pegmatites in New England suggests that the degree of rare mineralization of the pegmatites is directly proportional to the distance of the body from a normal granitic body.

Mineralogy of the Pegmatites

A comparison of the minerals observed in the Big Mine in Alstead, New Hampshire, with those found at Newry, Maine, and at Mt. Apatite, Auburn, Maine, will serve to demonstrate the pronounced differences between the Keene group of pegmatites and those of Maine.

Big Mine Alstead, N. H.	Newry Newry, Me.	Mt. Apatite Auburn, Maine
	Phosphates	
Manganapatite	Apatite	Apatite
Autunite	Autunite	Autunite
	Torbernite	
	Eosphorite	
	Triphylite	
	Heterosite	
	Lithiophilite	
	Reddingite	
	Vivianite	
	Herderite	Herderite
	Amblygonite	
	Beryllonite	
	Silicates	
Quartz	Quartz	Quartz
Albite	Albite	Albite
Microcline	Microcline	Microcline
Muscovite	Pollucite	Orthoclase
Biotite	Cookeite	Pollucite
Montmorillonite	Lepidolite	Cookeite
	Muscovite	Lepidolite
	Spodumene	Muscovite

Continued from page

Big Mine Alstead, N. H.	Newry Newry, Me.	Mt. Apatite Auburn, Maine
Beryl	Beryl	Beryl
Tourmaline (Black)	Tourmaline (colored)	Tourmaline
Cyrtolite	Zircon	Zircon
Garnet		Garnet
		Biotite
	Others	
Uraninite	Cassiterite	Cassiterite
Gummite	Columbite	Columbite
Columbite	Hatchettolite	Gahnite
Gold	Microlite	
Uranophane	Pyrochlore	Uranophane
	Siderite	Rhodochrosite

Palermo Pegmatite, North Groton, New Hampshire

In the general vicinity of the north end of Newfound Lake, New Hampshire, are a series of interesting pegmatites containing rare phosphates. In North Groton, for example, there are the Rice Mine, the Fletcher Mine, and the Palermo Mine. The Smith Mine in Alexandria is of the same general mineralogic type. The primary phosphate in these localities is triphylite. Some of the rare phosphates are direct alterations of the triphylite. Others are found in alteration veins in feldspar in no direct connection with the triphylite (apatite, amblygonite, brazilianite).

The Palermo pegmatite is probably the most interesting, mineralogically speaking, of New Hampshire pegmatites. A summary of most of the known minerals from this pegmatite follows, but it is of interest to point out that the pegmatite is also of considerable economic value. Unusually good mica has been removed. After the closing of the mine as a source of mica, it was reopened as a source of feldspar. Considerable beryl was also marketed with one of the beryl crystals attaining dimensions of 8' x 2'. In the process of spar mining several large triphylite crystals were exposed, the largest of these being about six feet across. The triphylite crystals showed all degrees of alteration from perfectly fresh material to cellular wad.

The alteration was accomplished by simple oxidation and by addition of water in the form of (OH) and H_2O. Lithium was lost during the alteration and calcium and carbon dioxide were introduced.

Triphylite - Li (Fe, Mn) (PO_4)
Pyrite, arsenopyrite, bornite
Wolfeite - (Fe, Mn) (PO_4) (OH)
Childrenite-eosphorite-(Fe, Mn) $Al(PO_4)(OH)_2 \cdot H_2O$
Xanthoxenite - $Ca_2Fe'''(PO_4)(OH) \cdot 1\frac{1}{2}H_2O$
Dufrenite - $Fe'', Fe''' (PO_4)_3(OH)_5 \cdot 2H_2O$

Graftonite- $(Fe,Mn,Ca)_3(PO_4)_2$

Fairfieldite - $Ca_2(Fe,Mn)(PO_4)_2 \cdot 2H_2O$
Reddingite - $(Fe,Mn)_3(PO_4)_2 \cdot 3H_2O$
Ludlamite - $Fe_3(PO_4)_2 \cdot 4H_2O$
Stewartite (?)
Vivianite - $Fe_3(PO_4)_2 \cdot 8H_2O$

Amblygonite $(Li,Na)Al(PO_4)(F,OH)$

Brazilianite $NaAl_3(PO_4)_2(OH)_4$

Apatite $Ca_5(PO_4)_3F$

Whitlockite $Ca_3(PO_4)_2$

Siderite $(Fe, Mn) CO_3$

Wad - hydrated manganese oxide

Potash feldspar

Albite - oligoclase
Muscovite
Quartz
Biotite - tourmaline (black)
Zinnwaldite
Cyrtolite
Radioactive autoxidation products.

The paragenetic sequence of the phosphates is not completely certain. In his discussion of the zonal distribution of minerals in the Palermo pegmatite, Frondel (1948) states:

"For the present description, the zones may be divided into three groups:

" (1) The outer zones of fine- to medium-grained-texture contain quartz, muscovite, biotite, plagioclase (oligoclase to albite) and black tourmaline.

" (2) The intermediate zone, coarse-grained, contains quartz, muscovite, biotite, albite, perthite, beryl, tourmaline, lazulite, other phosphates, and small amounts of sulfide minerals. The lower part of this zone has been worked for sheet-mica, and the upper part for feldspar and beryl. The beryl occurs in crystals up to eight feet long.

" (3) The quartz core, at the center of the pegmatite, contains several other minerals, especially at the edge. Single crystals of triphylite range up to fourteen feet or more in length, affording cleavage blocks several feet square. Large perthite crystals are found here; bronze scrap mica and blue-green beryl are present in smaller amounts. The brazilianite that was found in place occurred in cavities essentially at the contact of the intermediate zones and the quartz core."

The only phosphate which appears on the list and which has not been observed as being directly derived from triphylite is brazilianite. When observed in place in the quarry, brazilianite occurred in a vein-shaped alteration zone in mixed sugary feldspar and quartz. According to Frondel, the sequence of deposition in the narrow cavities which appeared in this zone was quartz-brazilianite-apatite-whitlockite-quarts. This vein which was practically vertical was located in potash spar which, in turn, overlay the quartz core. Although several large beryl crystals were to be found at

the contact between the quartz core and the feldspar in this vicinity, no triphylite masses were noted closer than fifteen feet in a lateral direction. Although whitlockite, amblygonite, and apatite have been observed in altered triphylite masses, other occurrences in feldspar have been noted; and it is relatively certain that the direct alteration of triphylite is not necessary for any or all of these minerals.

The alteration varied considerably in extent and in mineralogy from mass to mass of the grey blue triphylite. In some cases the only alteration was the formation of thin pods of wolfeite or thin open veinlets containing the fairfieldite, reddingite, ludlamite, stewartite (?), and vivianite sequence. Other crystals were altered so completely that no triphylite could be found. In this case the minerals to be noted were ludlamite, xanthoxenite, dufrenite, childrenite-eosphorite, apatite, whitlockite, siderite and wad.

Ruggles Mine, Grafton, New Hampshire

According to Bannerman, (1943)
"The general geological set-up of the Ruggles Mine is shown in Plate 1 (not included here). The country rock is quartz-mica staurolite schist. The strike of the schistosity is generally in the order of N 25° E to N 35° E, and the dip around 65 degrees eastward. Narrow, brownish weathering dikes of camptonite cut sharply across both schist and pegmatite in a northeasterly direction. The dikes dip steeply to the southeast. Their boundaries are sharp and they have a tendency to fork and to display an en echelon arrangement as though occupying joint fractures.

"The outcrop of pegmatite in which the main quarry is located is essentially an oblong lens 700 feet long and a maximum of 110 feet wide near the central part of the pit. This lens strikes N 35° E, and in the mine section it dips seventy-five to eighty degrees eastward. Just north of the quarry the outcrop bulges toward the east and south such that the outcrop pattern is somewhat the shape of an ancient battle-axe. The structure of this eastward protuberance cannot be told with any degree of certainty. It may be a fairly thin sheet dipping rather gently toward the east or it may be a diverging lens. Such data as are available favor the former interpretation. The outcrops which have been opened by mine workings south of the present workings are separated at the surface by screens of schist, but the pegmatite in which the main quarry is located and in which quarry number 2 (see Plate 1) is sunk, are one and the same, as is shown by the continuous section made possible by the mine workings, and it is not unlikely that some of those located farther down the hill toward the southeast are indeed continuations of the same body, the outcrops being carried eastward as they are followed down the hill because of the prevailing eastward dip. If this is so, then the general structure must rake at a gentle angle toward the south. The main trend is more or less parallel to that of the occluding schists, but in detail many of the apophyses transgress the schistose structure abruptly, accommodating themselves to the jointing and the shear pattern within the crumpled schists.

"The relationships of the various mineral deposits to the grosser structures of the pegmatite are shown in generalized form by the vertical sections of Figure 5 (not included here). Briefly, the mica concentrations occur in zones within a few feet of the walls and ceilings of the pegmatite and show maximum development where bends occur in the structure, such as at the curve in the roof on the second level just south of the main pit. The feldspar body is more or less centrally located, though it appears to come closer to the wall on the east (hanging wall) side of the deposit. Between the mica zone and the feldspar body, there is usually a shell of coarse graphic and sometimes of biotite-bearing pegmatite. The biotite zone is more prominent toward the north end where it forms a capping twenty-five to thirty feet thick on top of the feldspar body. The information at hand does not make clear the

direction in which the axes of these mineral concentrations rake within the dike, but such data as are available suggest that in the main they rake southward, parallel to the apparent plunge of the pegmatite itself.

"Large quartz veins of various ages break across the feldspar zone and small veins of white albite and quartz appear as a still later phase in the pegmatite sequence. Noteworthy among the quartz veins are occasional gobs of smoky quartz which have a general east-west trend and which are accompanied by a wide variety of unusual minerals, including many rare phosphates, uraninite and a long list of secondary uranium minerals. Cavities accompanying the albite contain montmorillonite, quartz crystals, occasionally aquamarine beryl, and many other minerals of interest to collectors. Common beryl also occurs sporadically with albite and quartz veins along the feldspar body. The list of minerals that occur in this deposit is long and because of this the mine dumps on the property have for many years been a favorite collecting ground for mineralogists and mineral fanciers. More detailed descriptions of the mineralogy of this deposit have been given in several previous publications."

Although more than thirty minerals have been reported from the Ruggles Mine, there is not really an extensive mineralization there. Occasionally, gummite, uranophane, autunite, torbernite and other products of radioactive disintegration have been found in distinct areas of concentration. These latter minerals were found in greatest concentration some years ago but are occasionally found, even at present, along a few fracture zones in the mine. The Ruggles Mine, like the Colony Mine, is an unusually large mass of potash spar.

Cameron et al. have noted that

"The role of replacement has been discussed by many investigators since the work of Schaller, Hess, Landes, Cook, and Müllbauer focussed attention on the problem. Out of this work has grown the conception that pegmatite development is accomplished in two main stages - a primary, magmatic stage of intrusion and crystallization of a fairly simple pegmatite, and a later state involving successive hydrothermal replacements.

"Field evidence gathered during the present investigation tends to confirm the prevailing concept of two main stages in pegmatite development. However, it seems clear that in zoned pegmatites the early stage was more complex than has been generally realized. The zones which determine the fundamental internal structures of most New England mica pegmatites and are the controlling element in mineral distribution appear in general to antedate the type of replacement, discussed by the investigators, cited above and evidently developed during the primary stage.

"Whether the zones developed in open or closed systems, and to what extent fractional crystallization, convection currents, dynamic influences, and other factors played a part are matters for later discussion. In the simplest case, the process appears to have been deposition of concentric shells inward from the walls of the chamber."

This statement is particularly true for the Alstead, Ruggles, and Palermo pegmatites, but many of the pegmatites of Oxford County, Maine, have been so complicated by later introduction and removal of materials that any earlier zoning is largely obscured.

Maine Pegmatites

Although individual pegmatites of the Newry, Paris, Auburn, and Topsham regions have been described in some detail, the paragenesis of most of them is very similar. As was suggested by Professor Charles Palache in his lectures long ago and ably

expressed by Landes in his treatment of the "Paragenesis of the Granite Pegmatites of Central Maine", mineralization of the pegmatites was accomplished in successive stages. The minerals deposited during each stage compose a distinct group or class." Landes then itemizes these stages as follows:

"I. During the first stage alone there was a mass crystallization from the liquid phase. The typical minerals of this class are potash feldspar (usually microcline), quartz, muscovite, biotite, black tourmaline, beryl, garnet, arsenopyrite, and manganapatite." (This is the phase of zonal development observed in the New Hampshire pegmatites - Note by author).

"II. This was followed at every deposit studied by a high temperature hydrothermal phase. The volatile constituents of the magma, which played a rather minor part in the first stage, now become of supreme importance. During the crystallization of successively lower portions of the magma, the 'mineralizers' are expelled and work upward, depositing new minerals as they do so. While the magma at hand and at slight depth was crystallizing, high temperature conditions prevailed, and the first class of hydrothermal minerals resulted. Typical minerals of this period are: quartz (usually in crystals), cleavlandite, lepidolite, lithia tourmaline, columbite, cassiterite, spodumene, and etched or pocket beryl.

"III. At Buckfield and to a very minor degree at Mount Mica and Auburn, an intermediate phase followed during which rare lithium-manganese phosphates were deposited by the ascending solutions. Typical products of this phase are: amblygonite, lithiophilite or triphylite, rhodochrosite, eosphorite or childrenite, fairfieldite, and reddingite." (Author's note. The triphylite at Palermo was probably formed during stage 1.).

"IV. A final hydrothermal phase which was very well developed at Buckfield, Greenwood and parts of Auburn resulted in the deposition of large amounts of cookeite and quartz. At Greenwood and Auburn purple apatite crystals were also formed in abundance. Typical minerals are quartz, cookeite, and apatite.

"V. Ground water alteration of material already present produced the last class of minerals. The minerals of this type are mainly kaolin and montmorillonite. Locally manganese oxides, dahllite, and francolite were formed.

"VI. The pockets of the Maine pegmatites are largely secondary, produced by dissolving activity of the same ascending solutions which deposited the rare minerals of the second and later classes."

Origin of the pegmatites

The two principal theories which have been suggest as explanations for pegmatites are that they are (1) acid differentiates of an acid magma; (2) products of solution and recrystallization of acid portions of surrounding country rock. The exposures which will be examined on this field trip will serve to demonstrate the applicability of these theories to actual pegmatites. Any satisfactory theory must explain the following observable facts.

1. Rare mineral pegmatites are most frequently associated with schists and gneisses which were originally sedimentary rocks. Nearby granite is not always observed, nor necessarily inferred.
2. Large pegmatite masses are very rarely found in igneous rocks.
3. Pegmatite masses which have been mined to their bases show no sign of feeding dikes or sills but are isolated bodies.
4. In some cases the mineralogy of pegmatites is monotonously uniform with quartz, potash feldspar, muscovite, and occasional spodumene.

5. The mineralogy of even adjacent pegmatites is often extremely varied.

6. Cavities and areas of alteration are so distributed in space and time of formation that the cause of the solution and alteration must be from outside the first formed pegmatite for the most part.

It would seem that the above statements may be explained by a combined but modified version of the theories mentioned above. The New England pegmatites are essentially a geosynclinal phenomenon. As the base of a geosyncline gradually sinks and sedimentary rocks accumulate to greater and greater thicknesses, the temperature of the lower sediments is considerably increased. The source of the heat need not be considered here. This increase in temperature is augmented by the blanketing effect of the overlying sediments. Connate water, with its wealth of dissolved chemicals, is present in the warming rocks. Water is also present in chemical combination in minerals such as kaolin, goethite, and others. The chemical composition of the sediments is extremely varied and contains many unusual elements such as manganese and uranium which are precipitated in peculiar and special submarine environments with particular varieties of sedimentary rocks. These chemicals are, of course, in addition to the minerals of the clastics which are derived from the weathering, erosion, assorting, and deposition of materials from land masses.

As the temperature increases, the aqueous environment makes possible the solution of such materials as quartz, potash and soda feldspars, muscovite, lithium, and boron-containing substances, and others before the major portions of the rocks are affected at all. In fact, in many cases much of the rock is unaffected by the solutional activity and remains as silica impoverished rock after the dissolved materials have been forced outward either under static or dynamic pressures. Obviously, however, if the temperature rises sufficiently, large sections of the basement and of the sedimentary rocks above the basement will be converted into magma. This is the major magmatic phase. The composition of this magma will vary considerably, depending on the final composition of the rock before it is converted into magma and in the degree of mixing of all the variable magmas as they are formed.

In general, the pegmatitic magmatic phase develops prior to the major magmatic phase. Acid differentiates do develop from the major magmas, however, and these form the pegmatite dikes and sheets associated with the New Hampshire magma series. It may be stated, then, that pegmatites are but one result of the general regional metamorphic process. By differential solution and recrystallization under different degrees of metamorphism quartz veins, pegmatites, various types of igneous rocks, and zonal metamophism are produced.

Emplacement of pegmatites

Regardless of the nature of orogenic forces, it is apparent that heated and partially dissolved geosynclinal rocks are more subject to deformation than others. At that moment when the strength of the rocks through heating and solution becomes inadequate to resist the orogenic forces, folding begins. The rocks are not completely fluid, but there is a notable liquid content. Without the orogenic forces (and, in some cases, even with them) the magmas will not flow nor gather into large chambers. A lit par lit type of structure would probably form if extended migration does not take place. But under the impact of orogenic forces, magmatic materials will move, concentrate, and be forced into positions of least hydrostatic pressure. In general, these positions will be conformable with the structure of the country rock, but many cases of cross-cutting will necessarily develop.

Pegmatite Variations

It seems apparent that there is no parent magma from which the pegmatites of an entire region have sprung. Their great variation could arise from a variable nature of source materials from which they have been derived. An examination of the rock types involved in the New Hampshire stratigraphic column given on page indicates the limits of variability of source material. Further variations are imposed by the nature of the conversion to magma. This differs with different concentrations of water, with different pressures, with different temperatures, and with different lengths of conversion time.

Thus a phosphate pegmatite, such as at Palermo, Branchville, Connectiuct, and Hagendorf, Bavaria (Müllbauer, 1925) would be explained, not by a peculiar differentiation of a homogeneous magma but by assuming that the unusual pegmatite material was derived from unique source materials which were rich in phosphate.

It would seem that the sequence of events in pegmatite formation is:

Stage 1 pegmatites. Solution of quartz, feldspar, and muscovite with subsequent recrystallization with or without much migration. This is the lit par lit and non-mineralized pegmatite stage. Many of the Oliverian magmas series pegmatites are of this sort.

Stage 2 pegmatites. Includes stage 1 but includes additional solution of beryllium, phosphorous, lithium, uranium, and other unusual elements followed by migration and injection. Pegmatites of this stage tend to be varied, depending on source conditions. This is the stage of zone formation. Two separate injections may be intruded into the same general region, producing complex zoning in such pegmatites. The New Hampshire pegmatites are largely representative of stage 2.

Stage 3 pegmatites. Stage 3 includes stage 2 but involves further solution in depth, releasing sodium, calcium, lithium, boron, carbon dioxide, and other substances of the so-called hydrothermal stage. Continued orogenesis opens and closes channel-ways and permits these solutions to pass upward into and through the stage two pegmatites. These pegmatites are largely those of Landes's stage IV and are typical of the Maine areas of Newry, Paris, and Auburn. The late mineralization phase at Palermo is indicative of this stage as well. The rising solutions bear substances which are thermodynamically less stable in solution than the already crystallized stage 2 minerals. In consequence, the quartz, potash feldspar, and other stage 2 minerals are partially or completely dissolved and stage 3 minerals are substituted. Where there is not volume-for-volume replacement, cavities remain which permit the crystallization of unusual crystal forms. There is a tendency for this replacement to occur near the contact with the somewhat impermeable roof of the pegmatite. Cavities and replacement veins are less common in the lower parts of large pegmatite masses.

The principal difference between this succession of events from that suggested by Landes and others is that the solutions which do the replacing are not residual from a crystallizing pegmatite magma. It would seem thermodynamically unsound to expect residual solutions to remove already crystallized substances. In a reaction series, substances may be dissolved, but the elements involved must enter into the lower temperature form. This is not the case in the usual picture of replacement in the pegmatites. Pegmatite dikes in granites which are derived from those granites by differentiation, rarely react with the already crystallized wall rock.

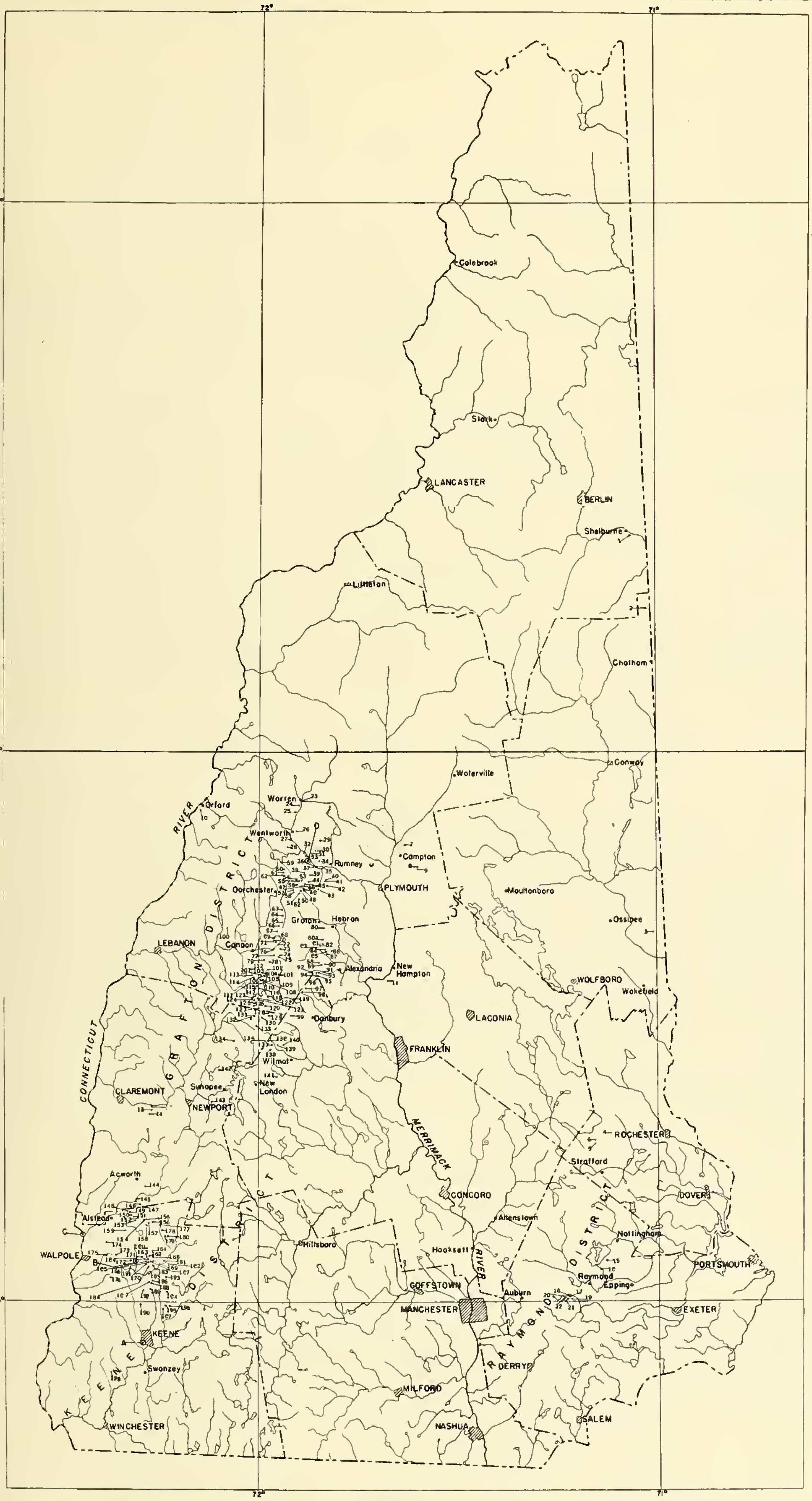
New Hampshire Pegmatite Localities

The map, Figure 5, which is included in this guidebook and which shows the location of feldspar deposits in New Hampshire, has been made available by the New Hampshire Planning and Development Commission from the work of J. C. Olson on "Feldspar and Associated Pegmatite Minerals in New Hampshire".

Maine Pegmatite Localities

Pegmatites of the Oxford County region of Maine are shown on Figure 6. The information thus plotted and the names of the pegmatite prospects or workings have been supplied by Mr. Stanley Perham of Trap Corner, Maine. Without his great store of knowledge concerning Maine Pegmatites and without his kind coöperation, this figure could not have been prepared. The pegmatites of the Topsham, Maine, area are not included because of scale trouble. The following locality numbers and names refer to Figure 6:

1. A. C. Perham Quarry
   1st feldspar developer
2. Witt Hill
   Chrysoberyl
3. Noyes Mt.
4. Willie Hiekkenen
5. Mattie Waisanen
6. Nesta Tammenen - Graftonite,
   excellent herderite, apatite,
   triphylite
7. Tammenen-Waisanen
8. Hayes Hill
9. O. M. Tammenen
10. Heath
11. Heath - Black tourmaline,
    rose quartz
12. Penley
13. Ruby Mine - Only genuine
    occurrence in Maine
14. Uncle Tom Mt. Big Mine
15. Uncle Tom Mt. Small Mine
    (purple apatite, herderite)
16. Uncle Tom Mt. Thomas Mine (largest
    pollucite crystal 21"x17"x19",
    herderite)
17. General Electric Mine (Quartz)
18. Scribner Ledge
19. Stearns Ledge
20. Guy Johnson Ledge
21. Andrew's Ledge
22. Roy Wardwell Ledge
23. Wentworth Ledge
24. Wentworth No. 2
25. Holt Ledge
26. Albany (Bumpus)
27. Mt. Mica old
28. Mt. Mica new
29. Mt. Mica quartz pit
30. Scott-Colby Ledge
31. Irish feldspar Ledge
32. Slattery Ledge
33. Bennett quarry (big)
34. Bennett quarry (orchard pit)
35. Cobbett Ledge
36. Killonen Ledge
37. Foster Ledge
38. 15 prospect quarries
    Little Singpold (Mt. Marie)
39. Harlow Ledges
40. Owl's Head pollucite deposit
41. General Electric pollucite mine
42. Westinghouse Pollucite Mine
43. Hibbs quarry
44. Prospects on #4 Hill
45. Mt. Rubellite
46. Cushman Ledge (new working)
47. Cushman tourmaline ledge
48. Cushman lithia spring
49. Sturtevant (feldspar)
50. Placer gold prospect
    (Hebron placer gold)
51. Pulsifer place
52. Keith Ledges
53. Maine tourmaline Co. Ledges
54. Greenlaugh tourmaline Ledges
55. Maine feldspar Ledges
56. McHugh Chrysoberyl locality
    (fair size)
57. Berry Mine (tourmaline)
58. Havey Mine (tourmaline)
59. Hatch farm
60. Tourmaline location (Western Ave.
    Auburn)
61. ? Pitts' cinnamon garnet locality
62. Wade tourmaline mine
63. Otis field gore (Sawyer
    farm-gem amethyst)
64. Otis field gore Brickett
    place amethyst
65. George Howe royal amethyst location
66. Bear Mt. Mica Mine
67. Beech Hill Mica Mine



INDEX TO MINES

SHELBURNE
1 Fischer
CHATHAM
2 Millard Chandler
WAKEFIELD
3 Weeks
STRAFFORD
4 John Felker
5 Parker Mountain
6 Ashton Rollins
THORNTON
7 White Mountain
CAMPTON
8 Upper Crystal
9 Lower Crystal
ORFORD
10 Woodward
NEW HAMPTON
11 Storer
NEWPORT
12 G F Smith
13 Chandler Mills
CLAREMONT
14 Sargeant
NOTTINGHAM
15 Carson
RAYMOND
16 Vatcher
17 Smith
18 Chandler
19 Smith No 2
20 Smith No.3
21 Welch
22 Blake
WARREN
23 Clement
24 Cotton
WENTWORTH
25 Fellows
26 Brown
27 New Gove
28 McGinnis
RUMNEY
29 Eight-Ball
30 Rogers
31 Belden
32 Leggett
33 Atwood
34 Keniston
35 Nickerson
36 Burgess
37 Ashley
GROTON
38 Burley
39 Union
40 Hackett
41 Valencia
42 Fletcher
43 Craylip
44 Nancy No.1 and No 2
45 Charles Davis
46 Plume
47 Mica Products Company
48 Palermo No.1
49 Palermo No 2
50 Palermo No 3
51 Rice
52 Pike Ledge
53 Pennsylvania Coal and Iron
54 Frank Davis
55 Diamond Ledge
56 Newt Kinney
57 Brown Lot
58 Brown Lot No.10
DORCHESTER
59 Hanley
60 Acme
61 Fairburn
62 Streeter Mountain
63 Rousseau
64 Kimball Hill
ORANGE
65 Keyes No 1 - No 6
66 Smith Pasture
67 Harry Ford
68 Pinnacle
69 Strain
70 Pettes
71 Standard
72 African
73 Boer
74 Hoyt Hill
75 Coleman
76 Staples
77 Williams
78 Summit Mica Mining Company
79 Whitehall prospect
HEBRON
80 Hobart Hill
80a Morgan
ALEXANDRIA
81 Marston
82 Akerman
83 Truman Patten
84 Monarch
85 Itaska
86 Standard
87 Wadhams-Tucker
88 Hutchins Hill
89 Pattuck
90 E.E.Smith
91 Mud
92 Braley Hill
DANBURY
93 Bailey
94 Jake Patten
95 Howe
96 Danbury
97 Pickwick
98 Wild Meadows
99 Stewart Hill
CANAAN
100 Stone
GRAFTON
101 Straw
102 Ruby
103 Buffum
104 Boardman
105 New Hill
106 Hole
107 Hammond
108 Whitehall prospect near Ruggles
109 Ruggles
110 Kilton
111 Prospect near Kilton
112 Thurman Powell
113 Prospect east of Spectacle Pond
114 Ed Cole
115 Evans
116 Alger
117 Glover
118 Rawlins
119 Sargent
120 Prescott
121 DeMott
122 Gage
123 Bennett
124 Carpenter
125 United
126 Saunders
SPRINGFIELD
127 Aaron Ledge
128 Columbia Gem Company
129 Reynolds
130 Playter
131 Colby
132 Melvin Hill
133 Globe
134 Justin Nichols
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135 North Star
136 Wilmot
137 Powell
139 Currier
140 Bog Mountain
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141 Elkins
SUNAPEE
142 Ledge Pond
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144 Johnson
145 Grant
146 Beryl Mountain
147 Balla
148 Yuhas No.1
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156 Lakin
157 Lyman
158 Fitzgibbon
159 George Porter
160 Britton
161 Smith Hill
162 Big
163 Tripp No.1
164 Island
165 Burroughs prospect
166 French
167 Blister
168 Kidder
169 Eames
170 Beauregard
171 Wheeler
172 Gates
173 Porter Brothers
WALPOLE
174 Damaziac
175 Chickering
176 Howe Ledge
MARLOW
177 Russell
178 Turner
179 Windham, West Cut
180 Windham, East Cut
181 Jones
GILSUM
182 Pamlaw
183 Converse
184 Nichols
185 Kirk No 2
186 Isham
187 High White
188 Jehial White
189 Kirk No 1
190 Fletcher
SURRY
191 Jack Reed
192 Surry Dam
SULLIVAN
193 Cary
194 Nims
195 Brooks
196 Price
197 Pelkey
SWANZEY
198 Aliber

INDEX TO MILLS

KEENE
A Golding-Keene Company
ALSTEAD
B Golding-Keene Company
WALPOLE
C J.F.Morton
WEST RUMNEY
D Northern Feldspars Inc

EXPLANATION

City or large town

Town or village

22 Mine location with index numbers

A Mill location with index letters

FIGURE 5. INDEX MAP SHOWING LOCATION OF FELDSPAR DEPOSITS IN NEW HAMPSHIRE
by Olson

10 0 10 20 30 MILES

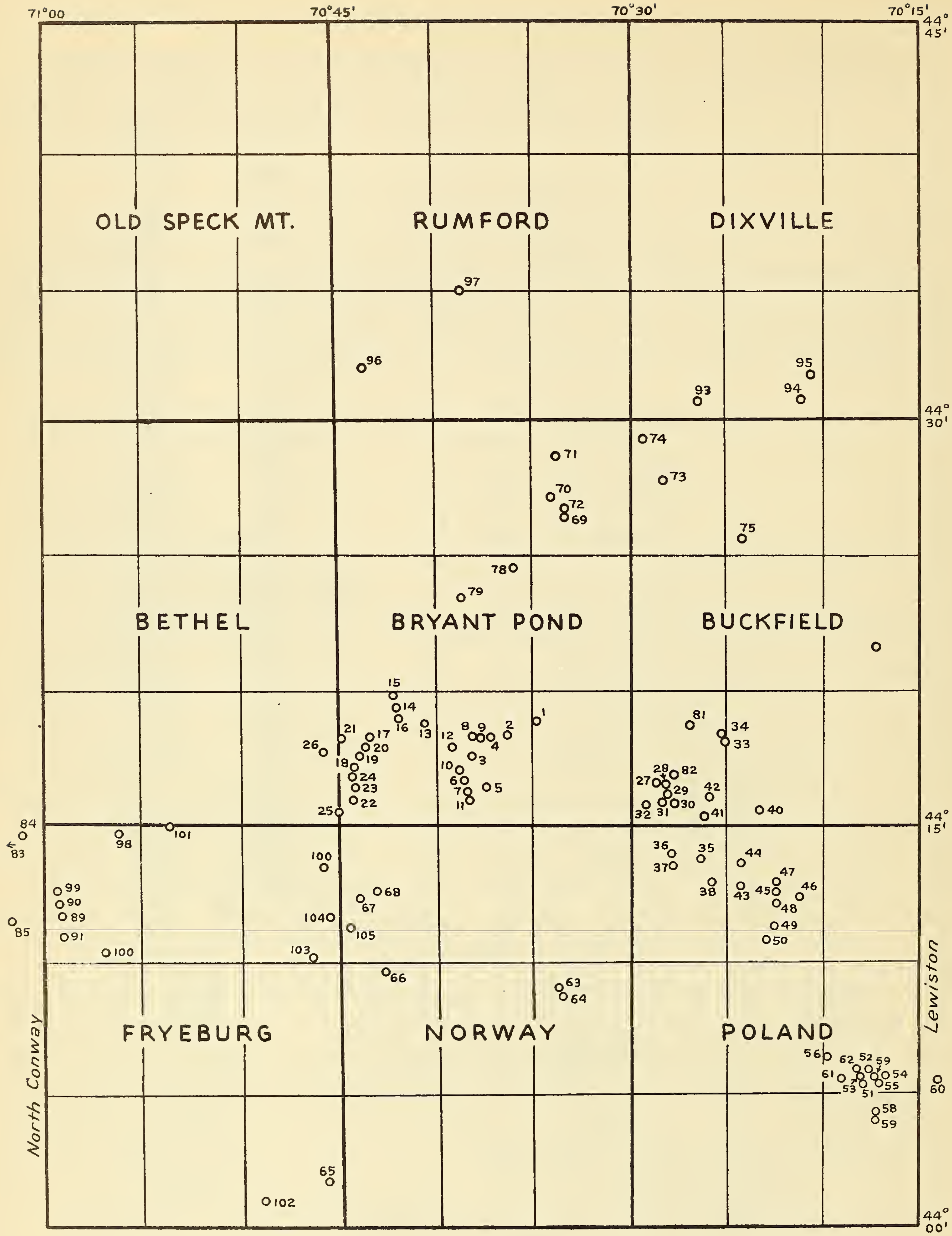

Figure 6. Pegmatite prospects and quarries of west central Maine. Data supplied by Stanley Perham of Trap Corner, Maine.

68. Kimball Mica Mine (large vein, small crystals)
69. Davis Mt. silver mine
70. Bean Mt. silver and lead mine
71. Mt. Zircon silver mine
72. Vesuvianite deposit
73. Hedge Hog Hill mine (golden beryl)
74. Lobikis mine
75. Ragged Jack chrysoberyl deposit
76. Bear Mt. mica deposit
77. ? Livermore Gold mine (actual removal)
78. Lone Star gold and silver mine
79. Cole Gore (gold nuggets out of turkey's crops)
80. Pot holes
81. Bessey Ledge (deepest around 135' - water)
82. Crocker Hill graphite
83. Topaz locality
84. Chandler beryl and feldspar
85. ? Fluorite deposit
86. Hurricane Mt. (Smoky qtz, crocidolite)
87. Lovejoy pits (at Conway - precious yellow topaz with feldspar crystals)
88. Redstone (fluorite, smoky quartz, feldspar crystals)
89. Little Deer Hill amethyst locality
90. Big Deer Hill amethyst locality
91. Lord Hill (Herderite, topaz, feldspar, phenacite)
92. Lead, zinc, silver (Carthage zinc mine)
93. Eberhardt Ledge (one of original purpurite find, spodumene tourmaline Also called Ferry fall or Hall's Ledges)
94.
95.
96, 97. Newry and Black Mt.
98. Melrose (Sugar Hill) Gem beryllonite
99. Coulton Hill (limonited pegmatite) lapis lazuli ?
100. Creeper Hill mica deposit
101. Willis Warren Ledge (fine strategic mica, beryl, 50 ton feldspar)
102. Georgia Howe (amethyst place)
103. Stearns Mt. Mica deposit
104. Beech Hill
105. Saunders Ledge (good mica)

Acknowledgments

The author wishes to extend his thanks to Mr. Charles Weeks of Meredith, New Hampshire, for his suggestions concerning New Hampshire pegmatites. Mr. Stanley Perham of Trap Corner, Maine, gave the author invaluable assistance and much time. The success of the Maine portion of the trip will be largely through his coöperation. The Golding-Keene Company and the Whitehall Company have been most generous in opening their quarry workings to the excursionists. The New Hampshire State Planning and Development Commission has provided original drawings and has permitted quoting from several of their publications. Quotations from the literature have been liberally used, and the author wishes to acknowledge the work of others in the field.

References

A complete bibliography of New Hampshire and Maine pegmatite literature will not be given here. Olson (1950) gives a thorough summary of New Hampshire literature on the subject. His paper may be obtained from the New Hampshire State Planning and Development Commission for 65 cents. The following bibliography includes those references directly referred to in the text plus a few others devoted to Maine pegmatites.

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Geologic maps of the several quadrangles from Keene to Mt. Washington have been prepared by Billings and his students and may be obtained from the New Hampshire State Planning and Development Commission, Concord, New Hampshire.

Itinerary for First Part of Trip

0.0 Boston University
First 2.5 miles are along the Charles River, which is an artificially dammed lake in this section. Most of this section is made ground. Harvard yard, to the north of the river, lies on an extensive Wisconsin outwash plain.

4.6 To the left, Fresh Pond, Cambridge Reservoir, in pit of outwash plain. To the right, deep varved clay pit excavated for brick making. For 1.5 miles our course leads over extensive valley train with peat bogs and lakes. The Mystic Lakes extend northward from this region, occupying a preglacial river valley. Western and northwestern edge of the Boston Basin looms in the distance.

7.0 Entering the highland region around Boston Basin. Rocks here are largely flows, probably late Devonian or early Carboniferous. Till cover in this region is relatively thin. General elevation of this upland region is 330'. This erosion level is so marked in eastern New England that there is some suspicion that it may be of marine origin.

9.1 Cut in typical Wisconsin till of the Boston area.

15.7 Across the low 330' upland of volcanic rocks, looking ahead down upon the extensive Concord outwash plain. In this pitted plain lies Walden Pond, famous for Thoreau's Walden. This outwash plain covers scores of square miles. With minor interruptions it extends for 20 miles.

20.0 Excellent drumlin looms ahead.

26.8 Another good drumlin.

31.8 Drumlin on left.

36.0 View of New England peneplain. Mt. Wachusett (a monadnock) on horizon to the left. Pronounced equal altitude terraces on either side of level summit are distinctive.

37.3 Nashua River. Extensive flood plain.

47.2 Entering second pronounced upland area at entrance to Willard Brook Parkway. Elevation at the base is 340'; elevation at summit lies between 900' and 1000'. Above this erosion level there is a rolling surface with a maximum relief of about 600'. The rocks here are mid paleozoic schists and gneisses.

75.7 Best view of Monadnock. This prototype of monadnocks is upheld by a rather pure Devonian quartzite. Pseudomorphs of muscovite after sillimanite are common in the quartzite.

77.0 Elevation of 930'; beginning of descent in Keene plain at distance of 85 miles lies at elevation of about 500'.

No road log will be given for remainder of trip.

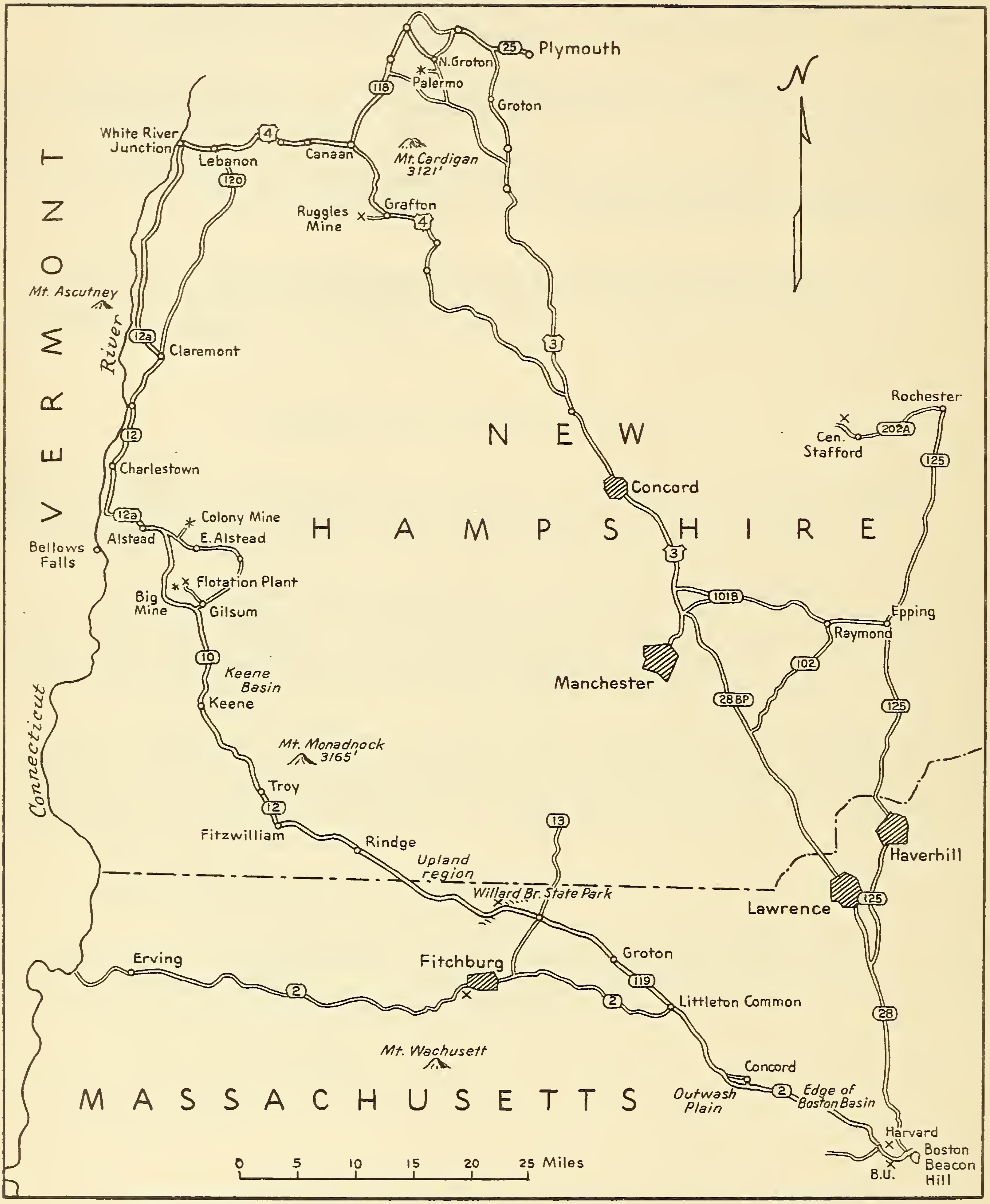

Figure 7. New England Pegmatites – Boston to Plymouth Road Map.

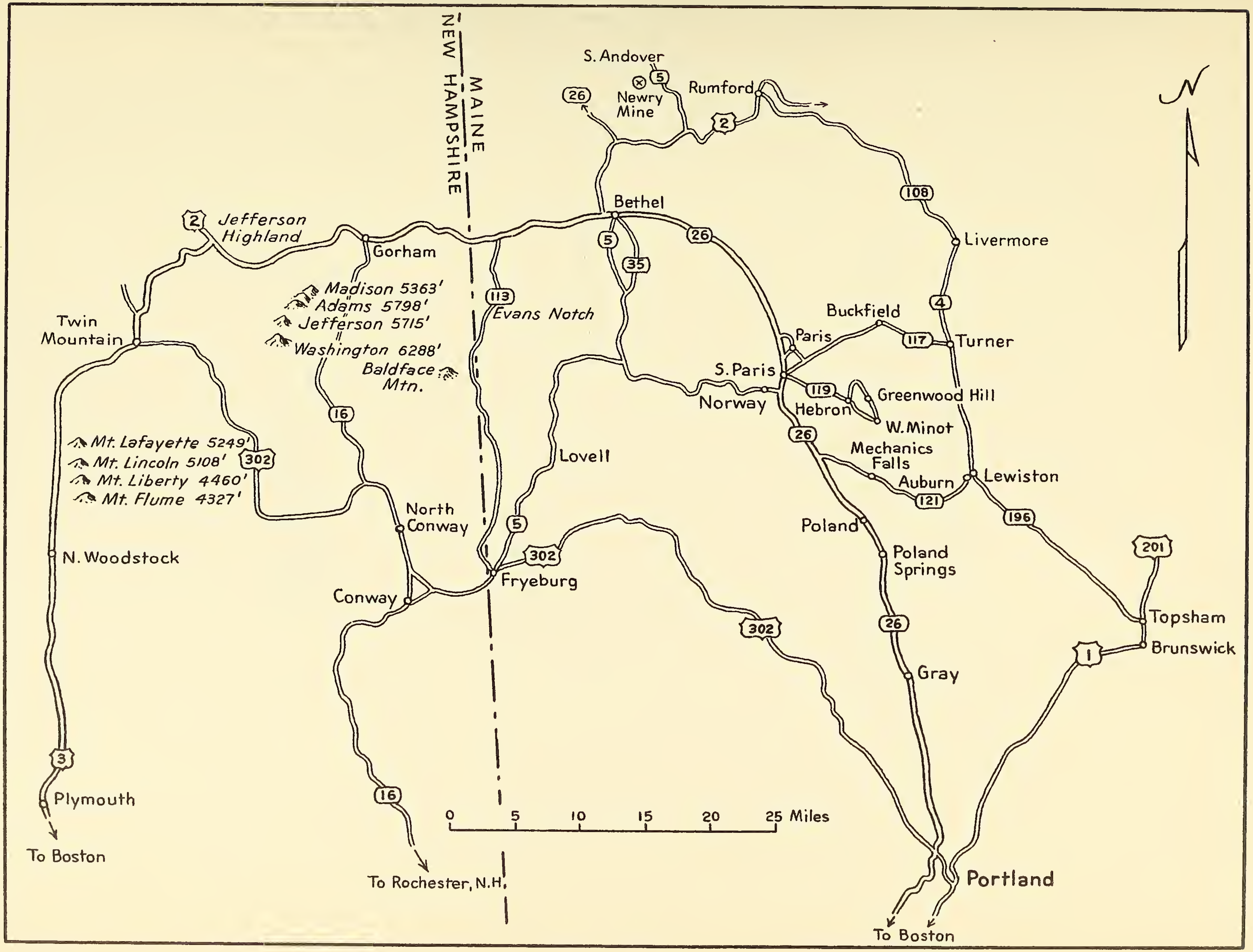

Figure 8. New England Pegmatites – Plymouth to Portland Road Map.

Field Trip No. 3

GEOLOGY OF THE "CHELMSFORD GRANITE" AREA

Leader: L. W. Currier
U. S. Geological Survey

CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE "CHELMSFORD GRANITE" AREA[1]

By L. W. Currier and R. H. Jahns

General Statement

By L. W. Currier

The purpose of this field trip is primarily to point out the stratigraphic and structural relations, and the megascopic features of the "Chelmsford granite."[2]

The writer's hypothesis is that the granite is largely or wholly of metasomatic origin, replacing sedimentary strata, and so represents a common facies of regional metamorphism. Emphasis is placed on structural and stratigraphic features. To that end, easily accessible exposures of the formations involved in the "setting" of the granite, and of the several metamorphic facies of the area will be visited. Available time and the mode of transportation, however, preclude the visiting of certain important localities, in particular the several quarries on Oak Hill (Tyngsboro quadrangle), and Snake Meadow Hill (Westford quadrangle), where some of the features of the granite are displayed to somewhat better advantage than in the Fletcher quarry. Geologists who are sufficiently interested in the problem could profitably spend a day or two in these localities.

The data upon which this paper is based have been collected intermittently through a period of eight years by several geologists attached to the Massachusetts cooperative geologic program. In 1937 the writer started a study of certain New England granites, and in the Westford district was assisted at various times by B. F. Buie, R. H. Jahns, and N. E. Chute. The study was continued in 1938, under the newly established geologic mapping program by the U. S. Geological Survey in cooperation with the Massachusetts Department of Public Works and the writer's general supervision. In 1939 detailed mapping of the Lowell, Billerica, Westford, and Tyngsboro quadrangles was started; this mapping was interrupted for a period of about five years by the War. Before and after this interruption the detailed bedrock mapping was done chiefly by R. H. Jahns and M. E. Willard, but several others assisted at various times for brief periods. It would not be possible to indicate exactly the extent of participation by the various geologists, but the major part of the mapping was done by R. H. Jahns (entire Lowell and Tyngsboro quadrangles, and part of Billerica quadrangle), and M. E. Willard (Westford quadrangle and part of Billerica quadrangle). W. S. White mapped part of the Billerica quadrangle and assisted for a short time on the Westford quadrangle.

Geologic maps of these four quadrangles and of the Ayer quadrangle, adjacent to the Westford quadrangle, (mapped by R. H. Jahns) are in preparation and will be published in the geologic quadrangle map series of the U. S. Geological Survey. More recently the mapping was extended to include the Maynard and Hudson quadrangles (W. R. Hansen), south of the Westford and Ayer quadrangles respectively.

The "Chelmsford granite" is exposed in an area about 13 to 15 miles long extending from Pelham, New Hampshire (Lowell quadrangle), southwesterly to the southeastern part of Groton, Massachusetts (Ayer quadrangle). The widest part of the

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[1] Publication authorized by the Director, U. S. Geological Survey.
[2] "Chelmsford granite" is a well-known commercial term, but it has no technical stratigraphic standing, nor is the term proposed as a stratigraphic name.

belt (approximately 2 miles) is the middle section, in Westford and Chelmsford (southern part of Tyngsboro quadrangle). It has been extensively quarried at several places in the central third of the belt, from Graniteville in Westford (Snake Meadow Hill, Westford quadrangle) to Dunstable Road (southeastern part of Tyngsboro quadrangle). The only continuously active quarry is that of the H. E. Fletcher Company, in Westford, about 2 miles west of North Chelmsford. The Oak Hill area northwest of the Fletcher quarry and Snake Meadow Hill at Graniteville both have several large inactive or intermittent quarries. Numerous small quarries and prospects are scattered elsewhere along the belt. The Fletcher quarry is by far the largest and deepest opening, and is considered by the industry to be one of the best-developed granite operations in the country. The most modern methods of quarrying are used here, and one of the striking features is the use of a specially constructed wire saw for releasing large blocks of stone with minumum loss and damage.

General Geology of the Region

By L. W. Currier

A geologic map of Massachusetts and Rhode Island was published in 1917 as part of a report on the geology of those states (Emerson, 1917). That part of Emerson's geologic map relating to northeastern Massachusetts, including the quadrangles involved in the subject of this field trip, was based almost entirely on the field work of Laurence LaForge. Emerson's text descriptions and discussions of the formations point out certain differences in genetic concepts of the age, metamorphism, and origin of the "gneisses and schists of undetermined age" which include certain beds of schist and paragneiss (originally called "Bolton gneiss" by Emerson - see section of this paper by R. H. Jahns below), and for which the term "Nashoba formation" has recently been proposed (Hansen, ms. in preparation).

The formations of this part of northeastern Massachusetts (Middlesex County and eastern Worcester County) consist chiefly of variably metamorphosed sedimentary rocks of late Paleozoic age and intruded late Paleozoic and Triassic (?) igneous rocks. Details of the lithology and stratigraphy for the "Chelmsford granite" region as worked out by R. H. Jahns for the Lowell, Tyngsboro, and Ayer quadrangles are given in a succeeding section of this paper.

In large part, and particularly in the area with which we are now concerned, the sedimentary formations consist chiefly of Carboniferous (and possibly Devonian?) arenaceous and argillaceous rocks, now quartzites, schists and paragneisses, that are exposed in roughly parallel belts of general northeasterly trend. These formations have been intruded in several places by large bodies of igneous, chiefly granitic, rocks.

The general column of metamorphosed sedimentary rocks for this part of Massachusetts is:

	("<u>Nashoba formation</u>" ("Bolton gneiss" and in part "gneisses and schists of undetermined age" of Emerson), biotite paragneiss and schist with amphibolite beds and marble lenses.
Probably Carbonife- rous	<u>Worcester phyllite-Brimfield schist</u>* (Emerson); phyllite facies and coal to southwest (Worcester basin), siliceous mica schist in places and and andalusite schist to northeast.

* The correlation of the Brimfield schist of this area with the Brimfield schist of the type locality southwest of Worcester is in doubt; the two areas are entirely unconnected and the stratigraphy of the original Brimfield belt has not been worked out sufficiently to correlate across the Worcester basin. There is considerable lithologic similarity between the Brimfield schist of the two belts, which is especially noticeable in the weathered outcrops.

(	Harvard conglomerate (Emerson); predominantly phyllitic or slaty matrix at Pin Hill, Harvard; with quartzite beds in places; schistose and feldspathized to northeast.
Devonian? or Carboniferous?	Merrimack quartzite (Emerson); probably Oakdale quartzite in Worcester area; thin quartzite and schist beds, more schistose to east.

The younger beds are toward the southeast. Dips are generally steep to vertical and rarely less than 70°. Locally, bedding dips are clear, but lack of recognizable repetitions of major units across the strike, widths of outcrop belts (especially of the "Nashoba formation"), and orientations of drag folds suggest that the major folds of the region are broader, more open folds, slightly overturned to the southeast. The area of present study, therefore, occupies the southeast limb of a regional anticline whose axis lies somewhat to the northwest.

To the southeast, in the southern part of Maynard quadrangle, the Marlboro formation (Emerson and Perry, 1907) is exposed in a flanking northeast trending belt. Emerson and others assign this formation to the pre-Cambrian (Algonkian), primarily on its lithology and degree of metamorphism. If the Marlboro formation in Maynard quadrangle is indeed pre-Cambrian, a fault of considerable magnitude must separate it from the adjacent "Nashoba formation" on the northwest. On the other hand, some geologists have recently entertained considerable doubt regarding the pre-Cambrian age of the Marlboro formation, in part because the metamorphism, lithology, and structure are similar in degree and types to the corresponding features of the late Paleozoic strata and in part because of the lack of any connection with other areas of presumed pre-Cambrian rocks in New England. Hansen (in preparation) notes that "the overall difference in appearance between the Marlboro formation and the Brimfield schist of the Harvard-Bolton area, in fact, is due more to differences in relative quantities of various rock types than to mineralogic differences." The Marlboro formation is, however, much more amphibolitic, a fact that may reflect the greater abundance of original limestones or volcanics or both, to the south. In this connection it is interesting to note that not only is the lithology of the Marlboro formation generally similar to that of the late Paleozoic rocks to the northwest (Brimfield schist and "Nashoba formation"), but the underlying sedimentary formation is of quartzitic character (Westboro quartzite); thus, if the Marlboro formation is late Paleozoic and not an upfaulted block of pre-Cambrian beds, it may well occupy the southeastern limb of the major syncline bordering the anticline mentioned in the preceding paragraph, as Hansen (in preparation) suggests. However, the stratigraphic problem (which appears to be thus so simply stated) is not so easily resolved as would seem, for the Westboro quartzite, is exposed only in relatively local areas south of the Marlboro formation, and it is largely cut out south of the belt of the Marlboro formation by granitic intrusions (chiefly Dedham granodiorite) whose age is a matter of current question and controversy, the age of the Dedham granodiorite being variously assigned from pre-Cambrian to Devonian.

At various places in the "Nashoba formation" local lenses of marble are exposed; these appear to be remnants of limestone beds that were sheared out. Mineralization of these marble lenses is indicated by various minerals, (Palache and Pinger, 1923; Emerson, 1917) including scapolites, boltonite (Bolton quarries) diopside, sulphides (pyrite, chalcopyrite, arsenopyrite, pyrrhotite), spinel, rutile, et al. In a marble lense located about 1½ miles southwest of Carlisle village is an old copper mine that was prospected in the early half of the 19th century.

Amphibolite layers appear along several belts in the "Nashoba formation." Some of these layers are persistent for several miles, and are remarkably uniform in width. Many others are small lenses. These amphibolite layers and lenses occur throughout the formation, and they are generally concordant with the bedding of the host. At

several places, lenses of marble lie within the amphibolite layers. In Boxborough, according to Hansen (in preparation), primary calcareous beds within the amphibolite indicate that it was derived from original limestones. He further points out that some of the amphibolite beds grade into impure marble, which also contains small grains of hornblende, zoisite, sphene, apatite, and brown mica. The idea is entertained that some--perhaps much-- of the amphibolite of the "Nashoba formation" has been derived from limestone beds.

The following section on the stratigraphy of the region has been contributed by R. H. Jahns, and is based upon his detailed mapping of the Lowell, Tyngsboro, and Ayer quadrangles.

Stratigraphy and Sequence of Igneous Rocks in the Lowell-Ayer Region, Massachusetts

By Richard H. Jahns

The oldest rocks in the Lowell-Ayer region of northeastern Massachusetts are of dominantly sedimentary origin, and are represented mainly by gneisses, schists, and quartzites of intermediate to high metamorphic rank. They are Paleozoic in age, and form a section many thousands of feet thick. The principal stratigraphic units, listed in order of decreasing age, are the Merrimack quartzite, the Harvard conglomerate, the Brimfield schist, and the "Bolton"* gneiss; their general features are summarized in the accompanying table. These units appear in broad, subparallel outcrop belts that can be traced northeastward from the Clinton-Harvard area through Lowell and Lawrence for distances of 50 to 70 miles into the northeast corner of Massachusetts and adjacent parts of New Hampshire. In addition, some of the strata appear to be traceable many miles beyond, into southwestern Maine.

Many original features of these rocks have been obscured or obliterated by metamorphism and by severe deformation on a small scale, and the continuity of most units is interrupted in places by masses of younger igneous rocks. In general, however, the stratigraphic units occur as a steeply dipping homoclinal series, and become progressively younger as they are traced across their strike from northwest to southeast. These age relations are demonstrated by attitudes of drag folds and other minor structural features, and especially by the Harvard conglomerate, which is basal to the Brimfield schist and contains pebbles that appear to be of Merrimack quartzite and other older formations. The "Bolton" gneiss evidently is the youngest of the stratigraphic units, and grades downward into the uppermost part of the Brimfield schist; its relatively "ancient appearance" is due mainly to injection and impregnation by much igneous material.

In broader structural terms, this metasedimentary series appears to form the southeastern flank of a major anticline that trends northeast and in general plunges southwest at moderate angles. This fold is complicated by numerous minor flexures,

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* Editor's note: Emerson applied the name "Bolton gneiss" at first to the thick section of paragneiss that overlies the Brimfield schist; on his map, however (because the name "Bolton" was preoccupied), he included it in his "gneisses and schists of undetermined age." W. R. Hansen, in collaboration and agreement with other workers in the area, proposes the name "Nashoba formation" in his manuscript on the geology of the Maynard and Hudson quadrangles, now being prepared for publication. (L.W.C.)

but its axis evidently extends through Clinton, Harvard, Ayer, and Tyngsboro, Mass., toward the Exeter-Dover area of New Hampshire.

The ages and correlations of the formations have not been established with certainty, owing chiefly to gaps in detailed mapping between the Worcester area in central Massachusetts and areas of fossiliferous rocks in southwestern Maine. On the basis of correlation with the Worcester phyllite, which reportedly contains plant fossils of Pennsylvanian age (Emerson, 1917, pp. 63-64), the Brimfield schist would appear to be Carboniferous; indeed, Emerson (1917, pp. 59, 78, 86-87) regarded all of the above-mentioned formations as Carboniferous in age. The Merrimack quartzite and Brimfield schist were traced farther northeastward by Keith, La Forge, and Katz, on this basis the presumably correlative Kittery and Eliot formations of southwestern Maine also were considered to be of Carboniferous age (Katz, 1917, p. 169).

More recently, however, attempts have been made to trace stratigraphic units southwestward from the Waterville, Maine, area, where Silurian beds are known (Perkins, 1924). Correlations from this direction suggest that the Kittery and Eliot formations cannot be younger than Silurian. This assignment of an earlier age is compatible with the stratigraphic relations in southeastern New Hampshire, where the Eliot formation (and presumably the Kittery as well) lies beneath the Littleton formation of Lower Devonian age (Freedman, 1950, pp. 475-476); on the other hand, it is not readily reconciled with the tracing of these beds or their equivalents into the Carboniferous strata of the Worcester, Mass., area to the southwest. These apparently incompatible relations must be resolved by further field studies.

The age determination of thw Worcester phyllite may be open to some question, based as it was on a few fragmentary plant fossils. Should the Worcester phyllite, Brimfield schist, and "Bolton" gneiss prove to be pre-Carboniferous in age, their general metamorphic rank and relations to igneous rocks would be much more in harmony with observed relations elsewhere in the eastern part of New England, as pointed out by Currier (1947, p. 85). An alternative possibility, for which there is some strong evidence, is that the belt of Worcester-Brimfield strata does not extend into the above-mentioned areas of older rocks in southeastern New Hampshire and southwestern Maine, but instead lies to the south of these areas. The Merrimack quartzite and associated strata, which can be traced northeastward into these areas with assurance, may be distinctly older than the Worcester phyllite and Brimfield schist, and the Harvard conglomerate thus may reflect a considerable interval of time.

As noted in the accompanying table, the igneous rocks of the Lowell-Ayer region are mainly late Paleozoic in age, and range in composition from norite to granite. In general the most basic rocks are the oldest. These include norites, gabbros, and diorites that form large composit instrusive masses in the towns of Dunstable, Lowell, and Dracut. The largest mass, in Dracut, has been described by Fairbanks (1927) and Dennen (1943). A distinctive diorite gneiss forms smaller, more widespread intrusive bodies that are highly elongate and essentially concordant, particularly where they occur within the broad belt of Merrimack quartzite and associated schists.

A somewhat younger complex of igneous rocks, known as the Ayer granite (or Ayer granodiorite), forms very large, elongate bodies that are parallel to the structure of the older metamorphic rocks. The principal masses lie in two subparallel belts that extend northeastward from Clinton through Harvard, Ayer, Westford, and Lowell, Mass., into southeastern New Hampshire. A very wide variety of rock types is represented, and some of the masses are plainly composite. Migmatitic rocks also are present, especially in the Ayer and Harvard areas, but in most other areas the rocks are intrusive (Jahns, 1942).

Large, highly irregular intrusive masses of binary granite crop out in the Townships of Dunstable, Mass., and Pelham, N. H. These are younger than the rocks of the Ayer complex.

A distinctly gneissic, generally leucocratic rock, known as the "Chelmsford granite," occurs as several isolated bodies and one very long, irregular mass that extends northeastward from Ayer through North Chelmsford, Mass., and into Pelham, N. H. (Jahns, 1943). It has been studied in some detail by Currier (1947, pp. 85-86), who believes that it represents the metasomatic replacement of schistose quartzitic beds of the Merrimack quartzite. In many places this granite is distinguished by thin, essentially parallel streaks and layers of contrasting mineralogy and texture, and these have been interpreted by Currier as relicts of original bedding in the replaced metasediments. Some other geologists, in contrast, favor the explanation of these layers in terms of a purely igneous origin. The border zones of the granite mass are characteristically pegmatitic and contain much rock that is plainly of hybrid origin.

The other igneous rocks in the region comprise small dikes and plugs of fine-grained granite; numerous irregular masses of pegmatite, aplite, and quartz; and simple dikes of diabase and camptonite. The masses of pegmatite and quartz are particularly widespread.

All the igneous rocks appear to postdate the Merrimack-Harvard-Brimfield sequence, and probably are younger than the "Bolton" gneiss as well. Most of them show well-developed planar structure that generally seems best interpreted as a result of flowage during intrusion and/or stress during crystallization. On the other hand, migmatitic rocks also are common, especially along the borders of the intrusive masses, and the boundaries between hybrid rocks and intrusive rocks are not easily distinguished in some places. This problem is particularly difficult in the "Chelmsford granite," much of which is marked by structures and textures that suggest unusual conditions of formation.

Principal Rock Units Exposed in the Lowell-Ayer Region, Massachusetts

By Richard H. Jahns

METAMORPHIC ROCKS, CHIEFLY OF SEDIMENTARY ORIGIN

(Middle and/or late Paleozoic in age)

Stratigraphic unit	Apparent thickness[1] (in feet)	General lithology
"Bolton" gneiss[2] ("Nashoba formation," see editorial note above)	At least 12,000	Light-gray, medium- to coarse-grained muscovite-biotite gneiss, with interlayered amphibolite, argillaceous

[1]Corrected for dips of beds, but not for structural repetition.
[2]Name assigned by Emerson, B. K., in Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, pp. 80-87, 1917.

		schists, and thin beds of marble; locally much contorted; commonly impregnated with igneous material, and contains dikes, pods, and stringers of quartz, aplite, pegmatite, and granite.
Brimfield schist[3]	3,600 - 6,800	Medium-gray (weathers rusty brown), fine to medium-grained sericite-muscovite-quartz schist, generally pyritic, with some amphibolite and biotite-, chloritoid-, andalusite-, and sillimanite-bearing layers; in some areas very uniform, and in others contains abundant layers of chloritic schist and micaceous quartzite toward base; generally plicated and contorted on a small scale; locally contains large masses of quartz and pegmatite.
Harvard conglomerate[4]	0 - 600	Interlayered medium-gray, dense, flaggy quartzite; medium- to dark-greenish-gray quartz-sericite-chlorite schist with some beds of pebble conglomerate; medium- to dark-gray phyllite and slate; minor thin beds of buff to greenish-gray calcareous schist; and thick masses of slaty-matrix conglomerate with pebbles and cobbles of dense, gray quartzite, slate, and white quartz; all units locally impregnated with much igneous material.
Merrimack quartzite[5]	At least 6,000, and probably much greater	Light-gray to greenish-gray quartzite, slaty quartzite, arenaceous phyllite and slate, and lime-silicate rocks, with interlayered brown and medium-gray feldspathic biotite schist, quartz-biotite schist, and hornblende-bearing schist; severely contorted in a few places; in some areas contains much igneous material and is locally gneissic.

[3] Name given by Emerson, B. K., in Geology of Old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden Counties: U. S. Geol. Survey Mon. 29, p. 17, 1898.

[4] Name given by Burbank, L. S., in On the conglomerate of Harvard, Massachusetts: Boston Soc. of Nat. Hist., Proc., vol. 18, pp. 224-225, 1876.

[5] Name assigned by Emerson, B. K., in Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, p. 58, 1917.

IGNEOUS AND HYBRID ROCKS

(Chiefly late Paleozoic in age)

Unit[6]	General lithology and form
Diabase	Dense, fine- to medium-grained diabase, mainly in simple dikes with considerable continuity; possibly Triassic in age.
Lamprophyre	Mainly very dark gray, medium-grained camptonite, in simple dikes
Pegmatite, aplite, and quartz	Light-colored, fine- to very coarse-grained rocks, in dikes sills, pods, and stringers; present in most of the other rock types.
Fine-grained granite	Light-gray, fine-grained quartz monzonite, somewhat gneissic, in many small intrusive masses.
Chelmsford granite[7]	Light-gray, medium-grained muscovite granite, locally porphyritic, in several large, elongate masses; distinctly gneissic; includes much coarse-grained migmatite near borders.
Binary granite	Light-gray, fine- to medium-grained biotite-muscovite granite, in small to very large irregular intrusive masses; locally pegmatitic.
Ayer granite[8]	Igneous complex with average composition of granodiorite. Comprises light-gray, medium- to coarse-grained granodiorite and quartz monzonite, commonly porphyritic; light- to medium-gray tonalite and granodiorite with abundant hornblende; medium-gray, fine- to medium-grained tonalite; and numerous migmatitic rock types; all rocks have distinct gneissic structure and form small to very large elongate masses.
Diorite	Medium-gray, fine- to medium-grained biotite-hornblende diorite gneiss, in small to large, very elongate masses; locally porphyritic.
Dracut diorite[9]	Igneous complex with average composition of gabbro. Comprises light- to dark-gray, fine- to coarse-grained norite, gabbro, and diorite, in thick intrusive masses; locally porphyritic, and in places marked by distinct gneissic structure.

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[6]Rock names are those in most common use in this region, and do not necessarily provide a petrographically accurate designation for the unit.

[7]Name given by Currier, L. W., in The problem of the Chelmsford, Massachusetts, granite: Amer. Geophys. Union Trans., 18th Ann. meeting, Pt. 1, pp. 260-261, 1937.

[8]Name given by Emerson, B. K., in Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, pp. 86, 223-228, 1917.

[9]Name given by Emerson, B. K., in Geology of Massachusetts and Rhode Island: U. S. Geol. Survey Bull. 597, pp. 221-223, 1917.

The "Chelmsford Granite"

By L. W. Currier

The problem of the "Chelmsford granite"* is one of genesis. Is the granite (1) entirely intrusive (and hence either magmatic or rheomorphic), (2) partly intrusive, partly metasomatic, or (3) entirely metasomatic? It would seem that (1) can be ruled out entirely because of certain structural and textural features that do not accord with magmatic or rheomorphic flowage. If this interpretation is accepted, we are concerned with the relative importance of metasomatic emplacement processes in developing the granite body in its present position.

The writer's working hypothesis is that the "Chelmsford granite" as we see it exposed is largely or entirely of metasomatic origin, and so represents a process and a facies of regional metamorphism that is common to the metamorphic areas of New England (Currier, 1947). One should be mindful also of Barrell's theories (Barrell, 1921) in this connection.

Many geologists have so confused migmatitization with metasomatic replacement that the term "migmatite" has been extended considerably from Sederholm's (Sederholm 1923, 1926, 1934) original definition. As he used it "migmatite" originally meant a mixture of magmatic material with country rocks of other origin. In his later work he somewhat broadened the concept by recognizing that solution, as well as injection of magma and anatexis, played an important part, but emphasis was placed on the presence of a magmatic (or neo-magmatic) phase to form a mixed rock. He acknowledged that chemical action was important, however, and that migmatitization was not necessarily the result of direct magmatic invasion. On the other hand, a current belief is that a metasomatic or replacement granite may be formed by hot solutions, which may, at least in part, arise from local magma basins at some depth, and that a mixture of the country rock with a magma is not required in the feldspathizing process commonly called "granitization."

The writer believes that direct infusion of magma, whether from deep-seated sources or by more local remelting, was not necessary; nor, indeed, is it clearly indicated in the principal exposed mass of the "Chelmsford granite," and hence that use of the term "migmatite" -- unless its broadened and loosened sense be generally accepted -- is inappropriate to this rock.

The mineralogy, textures, structures, and field relations of the "Chelmsford granite" as exposed in the various quarries in the Chelmsford - Westford belt seem not only to be entirely compatible with the idea of a metasomatic origin without flowage but some of the features are incompatible with a liquid or plastic condition. At present, the hypothesis of origin is based mostly on field observations, though some amount of petrographic study has been made. A more detailed and complete petrographic investigation is in progress. The writer is not entirely in accord, then, with the implication of Jahns' definition in the preceeding section on the igneous and hybrid rocks of the area. It is quite possible that some parts of the mass may be shown ultimately to be of magmatic origin, but the writer believes this is not required by the facts at hand and that the granite is a reconstituted, or replacement, rock rather than a hybrid.

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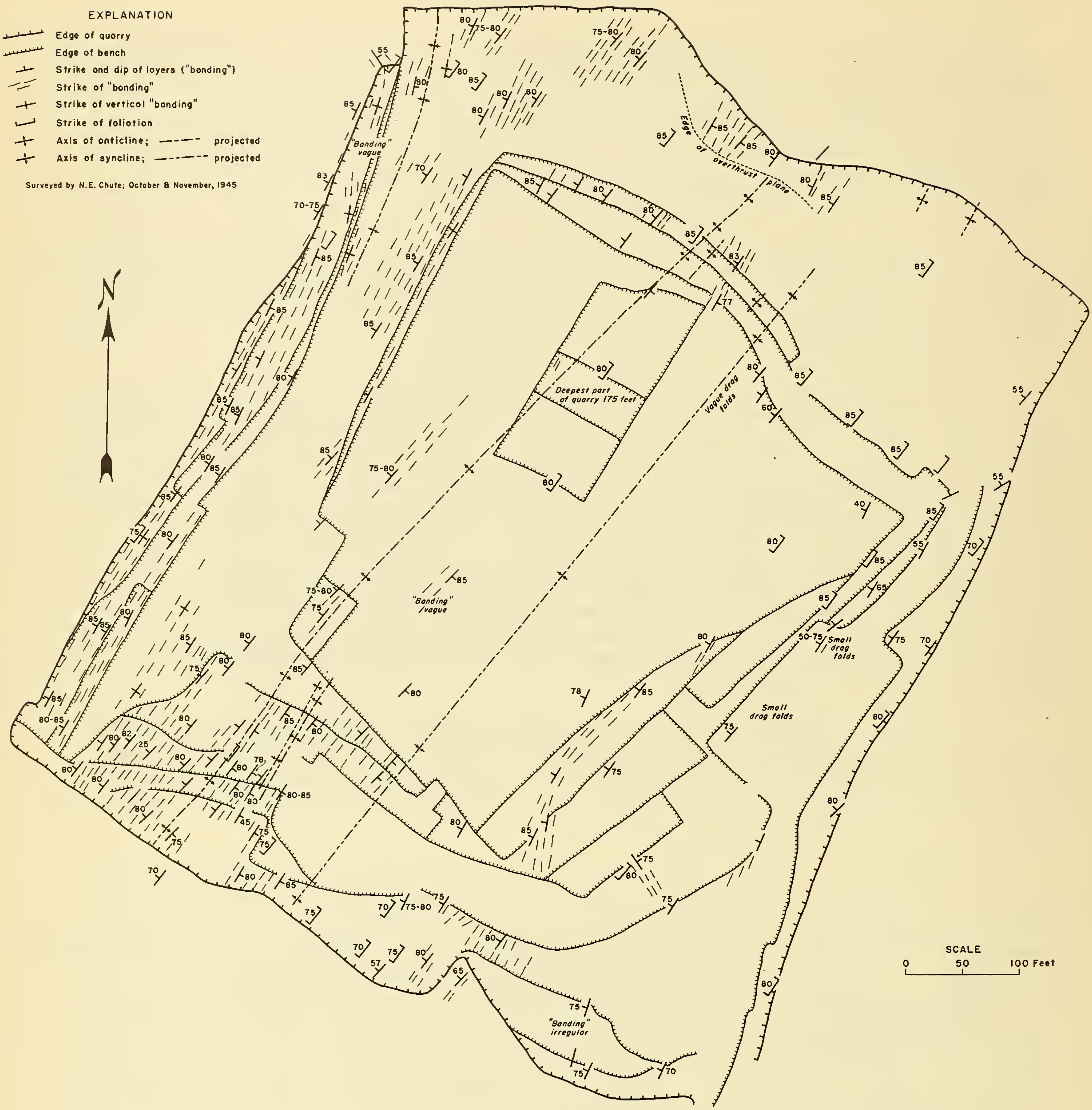
* The name "Chelmsford granite" is a commercial term and has no technical stratigraphic standing. On Emerson's map it is included in the area indicated as Ayer granite porphyry, together with several other granitic rock units or facies.



GEOLOGIC STRUCTURE MAP OF FLETCHER GRANITE QUARRY
WESTFORD, MASS.

Fig. 1

The "Chelmsford granite" occupies a position within the belt of outcrop of the Merrimack quartzite. Jahns' map* of the area (Tyngsboro and Westford quadrangles) and his description of the granite, as given in the preceding section, indicate a "migmatitic" zone between the granite and the quartzite, but no corresponding mixture along the contact zone of the "Chelmsford granite" with the Ayer granite. This implies that the Ayer granite may be later than the "Chelmsford granite," or that the Ayer granite was not affected by the invasion that produced the border "migmatitic" zone in the quartzite.

Whatever the source of the granitizing solutions that produced the "Chelmsford granite," their arrival from a magmatic source at some depth seems indicated by the mineralogy of the region, the abundant evidence, in the form of pegmatite, aplite, and quartz vein, of regional subjacent granite magma, and the abundance of intrusives of various types in the region. Such coincidences of igneous phenomena, metasomatic rocks, and pronounced regional metamorphism are characteristic of New England east of and including the Green Mountain-Berkshire highlands.

The layering of the granite as seen in the quarries is believed to be a relict of original layering of the host country rock. The layers are distinct, thin, remarkably uniform, and persistent. Folds are suggested by the attitudes of the layers (see accompanying map, Figure 1). On the crests of such folds the layers are vague, and in places may be wanting; here, too, the granite may be of coarser texture than elsewhere. In places a relict schistosity is superimposed on the layers that is apparently in an axial plane position and may be found to cut across the layers at a slight angle. Minor relict structures as small drag folds and displacements are to be found.

Schist and quartzite inclusions occur in the granite; these have been comparatively rare in the Fletcher quarry but have been found more abundantly in quarries on Oak Hill and at Graniteville. Quartzite inclusions are very few, and are apt to be composed of dense and relatively pure quartzite. Schist inclusions as well as the border zone are strongly biotitic. It is possible that these represent remnants of a "basic front" zone subsequently replaced by the gradually encroaching wave of granitizing solutions. To speculate further, the strong biotitization (and, in places, amphibolitization) of the "Nashoba formation" may indeed represent a basic front phenomenon associated with subjacent granitization not yet exposed by erosion as it is in the belt of the "Chelmsford granite."

Inclusions and layering of the granite mass conform with regional attitudes and trends of the formations.

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* Note: the geologic maps of the quadrangles involved are in process of compilation for future publication, and therefore, have not yet been released.

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Perkins, E. H. (1924) A new graptolite locality in central Maine, Am. Jour, Sci., ser. 5, vol. 8, p. 223-277.

Sederholm, J. J., On migmatites and associated pre-Cambrian rocks of southeast Finland: Bull. Comm. Geol. Finlande, nos. 58 (1923), 77 (1926), and 107 (1934).

Itinerary

Quadrangle maps required.--Ayer, Maynard, Westford, Billerica, Lowell, Tyngsboro; all Massachusetts, 7½ minute survey, scale 1:31,680, contour interval 10 feet.

Route.--Leave Boston 8:00 A.M. To traffic circle at West Concord, via Route 2; no stops.

West Concord circle, on Route 2 to Foster Street, Littleton: several exposures of the "Nashoba formation" (paragneiss) along this segment.

Continue west on Route 2; stops on Oak Hill to examine cuts in Brimfield schist ("Worcester formation") and at cuts west of Oak Hill to examine "Pingryville porphyry" (equivalent of Harvard conglomerate?). South on Ayer Road to Depot Street, west on Depot Street to cuts on Pin Hill (Harvard conglomerate).

Return via Ayer Road and Route 2 to Littleton Road; northeast and southeast on Littleton Road to Littleton; east to Littleton Common; southeast on Great Road ½ mile to exposures in "Nashoba formation."

Return to Littleton Common, thence east by north on Route 110 to Boston Road, left to Westford village, north by east on Depot Road to exposure of Harvard conglomerate ¼ mile northwest of Westford Station.

Return south by east along Providence Road to Route 110, east-northeast on Route 110 to exposures of "Nashoba formation" 3/4 mile west of Chelmsford Center.

Continue to Westford Center, thence north-northwest on Route 4 to exposure of Merrimack quartzite-Brimfield schist at junction of Routes 3 and 4.

Southeast $\frac{1}{2}$ mile on Route 3 to Westford Street. Follow Westford Street to Chelmsford Street, Lowell; southwest on Chelmsford Street $\frac{1}{2}$ mile to knob exposure of replacement pegmatite.

Return via Chelmsford Street to railroad station; thence via Fletcher Street and Pawtucket Street to Pawtucket Bridge, cross bridge (exposures of Merrimack quartzite), thence west on Pawtucket Boulevard about $6\frac{1}{2}$ miles to Tyngsboro Bridge; cross bridge; northwest on Route 3 to State line, (exposures of Merrimack quartzite).

Southeast on Route 3 to exposure $\frac{1}{2}$ mile south of Tyngsboro bridge, in migmatitic zone of Merrimack quartzite.

Northwest $\frac{1}{4}$ mile on Route 3 to Westford Road at Tyngsboro, southwest 3-3/4 miles on Tyngsboro Road, through Flints Corners, to Boston Road (at Flushing Pond), east by north on Groton Road 2 miles to Fletcher quarry (2:00 P.M.). Stop 1 to $1\frac{1}{2}$ hours at quarry.

From Fletcher quarry west $\frac{1}{4}$ mile on Groton Road to Whidden Corner; south on Oak Hill Road $1\frac{1}{2}$ miles to Graniteville Road at Brookside; east on Graniteville Road to exposures of andalusite schist (Brimfield schist) at junction with Westford Road.

Return to Boston via Route 4 through Chelmsford Center (exposure of Andover granite intrusive just north of Riverside at Concord River). Continue on Route 4 through Bedford and Lexington to Route 2, which follow through Cambridge to Boston.

Field Trip No. 4

GLACIAL GEOLOGY IN THE BUZZARDS BAY REGION AND WESTERN CAPE COD

Leader: Kirtley F. Mather,
Harvard University

ILLUSTRATIONS

GLACIAL GEOLOGY IN THE BUZZARDS BAY REGION AND WESTERN CAPE COD

By Kirtley F. Mather

The region south and southeast of Boston, to be traversed on this field trip is exceptionally favorable for observations bearing upon the manner in which a continental ice sheet may disappear from a region of relatively slight relief. The effects of stagnation of the ice during its retreatal stages are abundantly displayed for critical consideration, as well as the results of forward movement of the ice with frontal melting during brief intervals of renewed alimentation. Precise correlation of the successive micro-stages of ice retreat with the sub-stages of Wisconsin time recorded in the northern Mississippi Valley cannot at present be made, but it may be said in general that the deposits to be seen in this region are middle Wisconsin in age.

The bedrock surface across which ice from the Laurentian center advanced during Wisconsin time in this southeastern coastal portion of New England was characterized by numerous low hills, which with the exception of the Blue Hills, immediately south of the Boston Basin, were only a few score of feet in height. Much of the region was essentially the "inner lowland" of the Atlantic Coastal Plain. South and southeast of the Boston Basin, this erosion surface sloped gently downward toward the southeast. It had been developed on crystalline rocks of pre-Carboniferous age, mostly granitoid or diabasic intrusives and gneissoid or schistoid metamorphics. The "inner lowland" was bordered on the east and southeast by cuestas, formed of Cretaceous and Tertiary sedimentary rock (Johnson, 1925, pp. 105-117). Today these cuestas are submerged beneath the water of the Atlantic Ocean, but during the Wisconsin stage of the Pleistocene they were partly above sealevel and must have exerted a significant influence upon the movement and thickness of portions of the advancing ice-sheet.

This resulted in the development of a lobate form in the peripheral zone of the ice-sheet, and that form became more pronounced during the successive retreatal stages. In the area under observation during this field trip, two lobes of ice may be recognized: the Cape Cod Bay lobe toward the east and the Buzzards Bay lobe toward the west. Although these lobes of ice were confluent, they produced a cuspate pattern at the ice margin, and the ice in each lobe moved more-or-less independently of that in the other.

At its maximum spread, the ice responsible for the surface features of southeastern New England reached as far south as Nantucket and Martha's Vineyard. Here it built the well-known terminal moraine, fringed by a glacio-fluvial outwash plain, portions of which now stand above sealevel in those islands (Woodworth and Wigglesworth, 1934: Mather, Goldthwait and Thiesmeyer, 1940 and 1942). This moraine is believed by many geologists to be the eastward extension of the Ronkonkoma moraine on Long Island, New York.

The more important recessional stages in which the ice withdrew from this maximum coverage of the land are marked by a succession of frontal moraines, pitted outwash plains, and kame fields. These deposits have been identified and named in the following sequence:

Martha's Vineyard -- Nantucket terminal moraine and outwash plain.
Buzzards Bay (Buzzards Bay lobe) -- Sandwich (Cape Cod Bay lobe) moraine and Mashpee pitted plain.
Hog Rock (B.B. lobe) -- Ellisville (C.C.B. lobe) moraine and Wareham pitted plain.
Snipatuit kame moraine (B.B. lobe) -- Plymouth kamefield (C.C.B. lobe) and Kings Pond pitted plain.

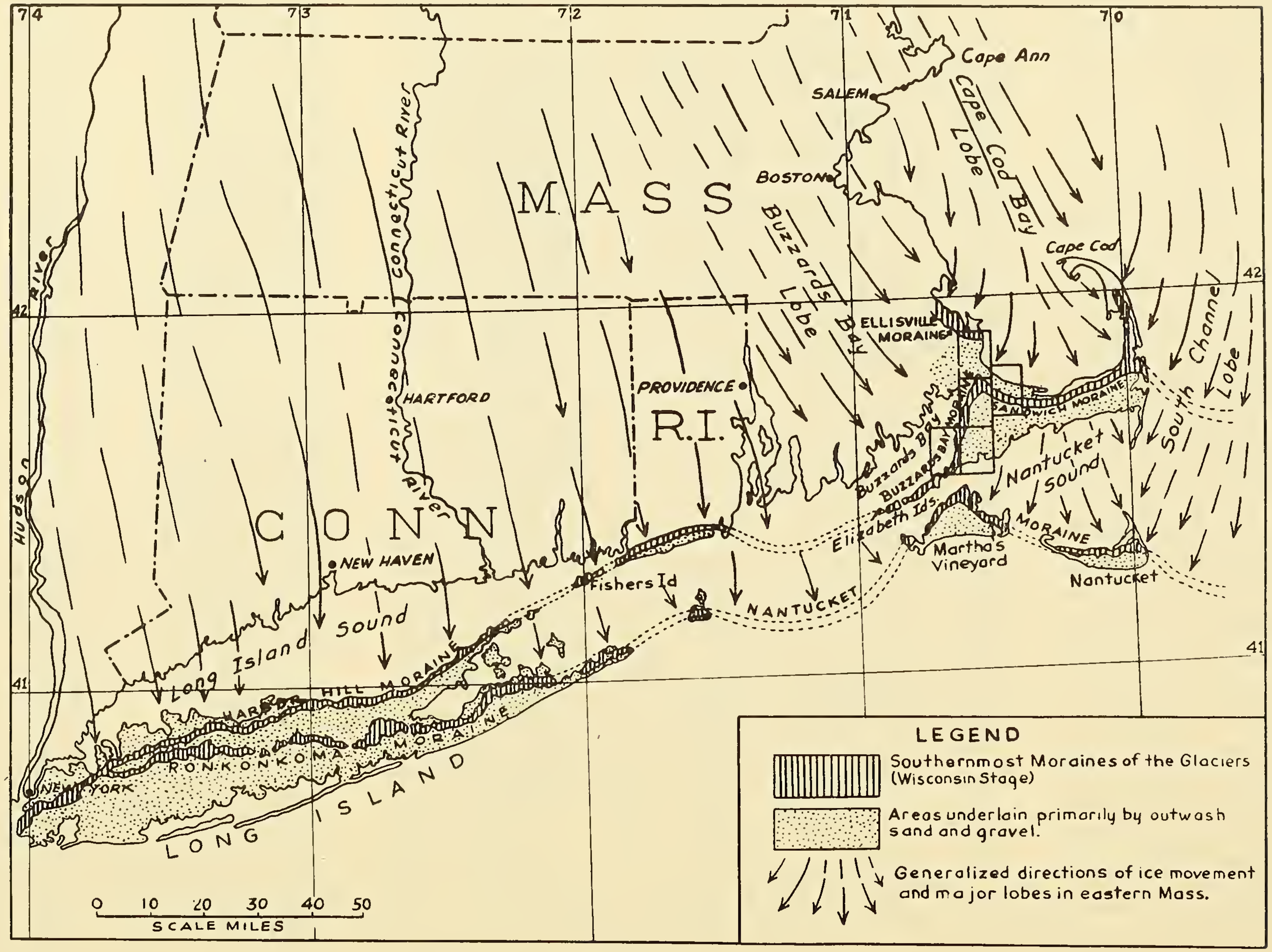


FIGURE 1

SKETCH MAP SHOWING MORAINES AND OUTWASH PLAIN AREAS OF SOUTHEASTERN NEW ENGLAND AND LONG ISLAND. THE INTERPRETATIONS OF GLACIAL FEATURES OUTSIDE THE QUADRANGLES SHOWN IN OUTLINE ARE THOSE OF M.L. FULLER, J.B. WOODWORTH, W.C. ALDEN AND, J.W. GOLDTHWAIT.

Middleborough kame moraine (B.B. lobe) -- Monks Hill moraine (C.C.B. lobe) and Carver pitted plain.

Plympton kamefield (B.B. lobe) -- Kingston kamefield (C.C.B. lobe), not bordered on the south be an extensive outwash plain.

Moraines, kamefields and outwash deposits, north of latitude $42^{\circ}00'$, not yet mapped in detail.

Several of the named features in this sequence will be seen on this field trip. Each will be described and its origin considered, in the order imposed by the route to be followed. This in general will be from the bottom toward the top of the list given above, inasmuch as the field party will travel southward into and across the area in which these features are displayed.

Field Log

Lve Hotel Statler, 8:00 a.m.

Route to Neponset Circle, about 5 miles, will depend upon traffic conditions.

Mileage

0.0 Neponset Circle, southeast across Neponset River on Route 3.

0.3 Squantum Head beyond U. S. Naval Reservation at nine o'clock.

2.3 Turn left with Route 3 on "Southern Artery," through Wollaston.

3.1 Cross major highway. Occasional glimpses of drumlins forming islands in Boston Harbor at nine o'clock. You are now in Quincy.

4.1 Route 3A turns to left; continue south on 3.

4.7 Curve left.

4.9 Fore River Shipyard (Bethlehem Steel Co.) at nine o'clock. You are now in East Braintree.

6.2 Cross Fore River and enter Weymouth.

7.6 Keep Route 3; Route 18 forks to right.

8.6 Whitman's Pond at nine o'clock.

9.2 Through Lovell Corners.

11.0 Route 128 joins Route 3 from right.

11.9 Keep Route 3; Route 128 turns to left.

13.6 Breezy Bend.

14.1 Assinippi (Route 123 crosses 3)

16.7 Cut in glacio-fluvial gravel at nine o'clock.

17.7 Route 139 joins 3 from right.

18.4 Cross North River.

18.7 Route 139 leaves 3 to left.

19.9 Cross Herring River (Pudding Brook on USGS map)

22.2 Leave Pembroke, enter Duxbury.

23.0 - 23.7 Kamefield with cranberry bogs, several on right, two small ones on left.

24.0 - 25.1 Crossing extensive sand plain.

25.9 Leave Duxbury, enter Kingston. Kamefield.

26.6 Climbing ice-contact slope to summit of sand plain.

26.7 Route 3A joins 3 from left, on sand plain sloping gently southward.

26.9 Captains Hill (drumlin) topped by Myles Standish Monument may be seen across Kingston Bay at eight o'clock.

27.2 Cross railroad in Kingston.

27.4 Climbing another ice-contact slope which can be seen best at two to four o'clock.

27.7 Descending gentle southward slope of sand plain, steepened by post-glacial stream erosion, to

28.0 Jones River.

The sand plain just crossed is the northernmost part of the Kingston kamefield which extends southward 1.5 miles from Jones River to the northern edge of the Monks Hill moraine and eastward to the shore of Plymouth Bay between Rocky Nook and North Plymouth. The materials of this area are cross-bedded and steeply bedded gravel and sand, subangular and poorly sorted, with scattered boulders and some interstratified glacio-lacustrine silt. In the southern and central sections of this kamefield the summits of the knobs and ridges vary in altitude from 165 to about 210 feet. Northward, however, the hills are progressively lower and near the coast they are less than 50 feet in altitude. The ridges show a general east-west alignment and elongation. In addition to the slope ascended at 27.4, there are at least three other rather steep and fairly straight northward facing slopes within this kamefield which are interpreted as ice-contacts along which elongate kames were built. These slopes are in general at successively lower elevations northward from the southern margin of the kamefield. They therefore suggest a northward retreat of the ice border through thinning of an almost stagnant mass of ice.

On the other hand, a part of the kamefield which will be traversed between miles 53.1 and 53.9, is blanketed by a till veneer ranging up to 20 feet in thickness. Here the topography is somewhat smoother than elsewhere and the surface is liberally sprinkled with large erratics. Pits and roadcuts expose a veneer of loose, sandy till at some places and compact gray "hardpan"

till at others, overlying typical kame deposits. The till was spread very unevenly over the area and in places it was so thin that recent erosion has already cut through it. This till veneer suggests that an appropriate part of the Cape Cod Bay ice-lobe was sufficiently active to shove forward after the interval of stagnation and over-ride the glacio-fluvial deposits made during that interval of time. There are several places in this modified portion of the kamefield where the beds of sand and gravel have been deformed by the re-advancing ice. Layers of sand have been shoved into a vertical position and then doubled over into an S-shaped curve at the top. Presumably such folding was produced in the unconsolidated sand when it was saturated and frozen into a mass that could behave as a plastic unit responding to slowly applied but great pressure.

28.3 Keep left of Route 3A; Route 3 leaves to right.

29.2 Turn left on Howland's Lane.

29.6 Turn right on East Avenue.

29.9 <u>Stop No. 1</u>. Rocky Nook Point.

Between the road and Kingston Bay, there is the last outcrop of bedrock as one traverses the coast of Massachusetts southeastward from Boston toward Cape Cod. There are no bedrock outcrops on the Cape itself. Rocky Nook Point is a low ice-smoothed hill of granite, thinly veneered with till. The granite is a part of the Dedham granodiorite complex. There are numerous exposures of it along the shore of the Point northwestward from this place, as well as in low knobs and hillside ledges, 0.5 to 1.5 miles to the west.

The low bluffs along the shore reveal bluish to rusty-brown till lying directly upon the ice-smoothed granite. The lowermost 4 to 8 inches of the till is compact "hardpan" with a distinct pseudolamination and a streaked appearance. Above this basal portion, the till is coarser and grades upward into gray sandy till at the top. The stones in the lower compact till are no more weathered than those in the loose till above. The coloration of the basal material is presumably related to infiltration of ground water which migrated along the contact with the relatively impermiable rock beneath and brought about a good deal of oxidation and concentration of iron-bearing mineral fragments to stain the till a rusty brown. The pseudolamination may be a result of processes operating when the till was spread beneath the ice load as a plaster over the bedrock. There seems to be no reason to postulate two tills of different ages at this place.

The granite bears glacial striae oriented south 25 degrees west. The till is interpreted as a part of the ground moraine of the Cape Cod Bay lobe. It may have been spread at the base of advancing ice and thus be older than the glacio-fluvial materials of the Kingston kamefield, or it may have been deposited by retreating ice and thus be of approximately the same age as those materials.

Facing the Bay one may see the Myles Standish Monument on the summit of Captains Hill at the left and in sequence toward the right three other wave-cut drumlins: Clarks Island, Gurnet Point with its lighthouse, and Saquish Head. Farther to the right is Duxbury Pier lighthouse and then the end of Plymouth Beach.

30.0 Turn left.

30.3 Turn left and return to Route 3A.

31.0 Turn left on Route 3A (same corner as 29.2).

31.5 Enter North Plymouth.
Plymouth Cordage Plant on left.

32.6 Plymouth Beach beyond Plymouth Harbor at ten o'clock.

33.2 Pilgrim Monument on hill beyond houses at two o'clock.

33.5 Turn left at junction with Route 44 and follow signs to

34.1 Plymouth Rock. Stop No. 2.

Plymouth Rock is a glacial erratic presumably plucked from a ledge of Dedham granodiorite now submerged in Plymouth Bay. It had been incorporated in the gravel of the Plymouth kamefield and then was left at the shoreline by wave erosion.

34.1 Return to Route 44.

34.8 Keep on Route 44 across Route 3A. (Same intersection as 33.5.)

You are now crossing the Plymouth kamefield. Its hills and hollows occupy an area some 5.5 miles long from southeast to northwest and varying in width from about a mile to a little more than three miles. It is bordered on the east by Pine Hills, on the north by the shore of Plymouth Bay, on the northwest by the Kingston kamefield and Monks Hill moraine, on the west by the Carver pitted plain, and on the south by the generally higher ground of the Symington kame moraine, which may be considered to be a part of the Ellisville moraine, and the northern ends of the Hog Rock moraine and Kings Pond plain. As indicted by its topography and the materials of which it is made, it is not a simple recessional moraine, although it doubtless defines the margin of the Cape Cod Bay ice-lobe at one stage in its withdrawal.

Many of the higher portions of the Plymouth kamefield are elongate ridges with almost flat summits. The altitude of the hilltops decreases northward from about 180 feet near the southern margin of the area to just over 100 feet near the shore at Plymouth. The landscape is characterized by a great number of kettle holes, large and small, closely spaced or widely scattered, and completely unsystematic in their arrangement.

The material of the kamefield is everywhere stratified glacio-fluvial silt, sand, gravel, cobblestones and boulders. Nearly everywhere these sediments display steep bedding, cross-bedding and channeling. At many localities they are poorly sorted; cobbles occur in the midst of fine sand, and boulders up to three feet in diameter are embedded in fine gravel. There is no systematic gradation in texture in any direction.

The Plymouth kamefield is interpreted as the result of deposition during the melting of stagnant ice, the drainage from which was blocked by deposits at its margin. Much of its materials accumulated on the uneven surface of the dwindling ice and on the ground between the shrinking remnants of the ice-sheet. The narrow peninsulas that now jut into the ponds (Hathaway Point in Billington Sea, for example), the narrow ridges that separate several of the closely adjacent ponds, and the island in Billington Sea were constructed of washed debris that clogged expanding crevasses in the stagnant ice. Many lines of evidence converge to indicate complete stagnation of the ice for a considerable interval of time, during which deposition occurred simultaneously in various parts of the kamefield area.

Presumably the highland of the Pine Hills was related genetically to the development of this extensive kamefield. Nowhere else in this part of Massachusetts is there a similar high elongate obstruction or a similar large kamefield. With respect to the direction of ice movement, much of the Plymouth

kamefield lies in the lee of Pine Hills. Other portions of the Cape Cod Bay lobe, not in the lee of such an obstruction, or in the lee of only its lower portion, were actively moving and formed normal recessional deposits, the Ellisville moraine, Monks Hill moraine and associated outwash sediments.

The extent of the kamefield westward from the Pine Hills suggests that the obstructing ridge must originally have extended some distance north of Rocky Point. A line drawn from the western edge of the kamefield northeastward parallel to the striae on the bedrock ledges at Stop No. 1 (presumably the general direction of the advance of the ice) intersects the northward extension of Pine Hills about 8 miles north of Rocky Point. (Not to be confused with Rocky Nook Point. Rocky Point is 4 miles east of Plymouth.) This may be a maximum figure because it does not take into account a possible westward bend in the direction of ice movement. It is clear that the northern end of Pine Hills, exposed to vigorous wave action, must inevitably have been cut back quite a distance in the thousands of years that have elapsed since the ice disappeared from this region. An idea of the amount and rate of present erosion may be gained from the fact that the land survey maps at Manomet Point, a mile and a half farther east, indicate that the cliffs on the north side stood 75 feet farther north in 1895 than they do today. Time enough has elapsed since the ice withdrew from this region to permit several miles of retreat at that rate. In any case, a very bouldery pavement, such as is derived from erosion of bluffs of till, continues north of Pine Hills for at least 3/4 of a mile, and is exposed to view during exceptionally low tide.

As might be expected, there were ephemeral ponds and lakes at many places in the kamefield area into which glacio-lacustrine sediments were poured. With moraines and high apices of outwash plains to block southward drainage, with kames and bodies of stagnant ice standing here and there, the drainage from such a ragged downwasting glacier could not possibly escape local, temporary damming. At many places there are local deposits of finely laminated silts, or of well-sorted, evenly stratified, fine sands almost free of pebble streaks. Commonly these show tiny oscillation ripplemarks through a considerable vertical range. Such deposits indicate deposition in the quiet waters of local ponds at some distance from receding ice or in a region of periodically sluggish drainage. The best exposures of such glacio-lacustrine deposits occur in the wave-cut bluffs of the shoreline where, at two localities, excellent sections of varved clays and silts occur in the midst of glacio-fluvial deposits.

35.5 Underpass beneath Route 3.

36.0 Curve slightly to right.

The higher hills of the Monks Hill moraine may be glimpsed through the trees at two o'clock as you approach this curve and at one o'clock immediately after rounding it.

36.2 Curve to left.

36.3 - 36.4 Cross southeastern end of Monks Hill moraine. From this point onward for several miles you will be traversing the Carver pitted plain.

The Monks Hill moraine extends in a northwesterly direction from Route 44 for 1.5 miles and then curves due westward for another 2 miles. Along much of its southern front it stands 40 to 80 feet above the northern margin of the Carver plain. It varies in width from 3/4 to 1-1/4 miles, is unusually rocky and has an extremely hummocky surface. It is named from Monks Hill, its highest knob, standing at an altitude of 314 feet. Like other moraines of

southeastern Massachusetts, this one appears to be composed primarily of loose sandy till. On the north the moraine merges topographically with the Kingston kamefield.

Southeastward curvature of the moraine front in its eastern portion and of the ridges in this section indicates some irregularity in the ice margin and probably some local change in the direction of forward motion of the ice. Orientation of the morainic belt and of the parallel ridges within it shows that at least its eastern part was formed by ice of the Cape Cod Bay lobe. This is further suggested by two clearly defined ice contact slopes within the moraine. One forms the east side of the hill on which Nicks Rock is located, and the other forms the steep northwest side of the 268 foot hill north of North Triangle Pond. These slopes face each other and converge southwestward. They apparently define a wedge or tongue of ice that shoved southwestward in this district. It is evident that this moraine was built after the Buzzards Bay lobe had disappeared from the area of the Carver plain, but while ice still lingered over the site of the Plymouth kamefield.

An ice contact slope at the eastern end of the moraine indicates an abrupt change from the dead ice of the kamefield area to the active ice that produced the moraine. It is interesting to note, further, that following construction of the moraine the ice also lay stagnant to the north of it for some time while the extensive Kingston kamefield was formed.

The Carver pitted plain occupies about 30 square miles of the Plymouth, Plympton and Snipatuit Pond quadrangles, stretching southwestward from the Monks Hill moraine and the Plymouth kamefield. It is typical of the several, extensive, pitted outwash plains constructed during the waning stages of the Wisconsin ice in southeastern Massachusetts.

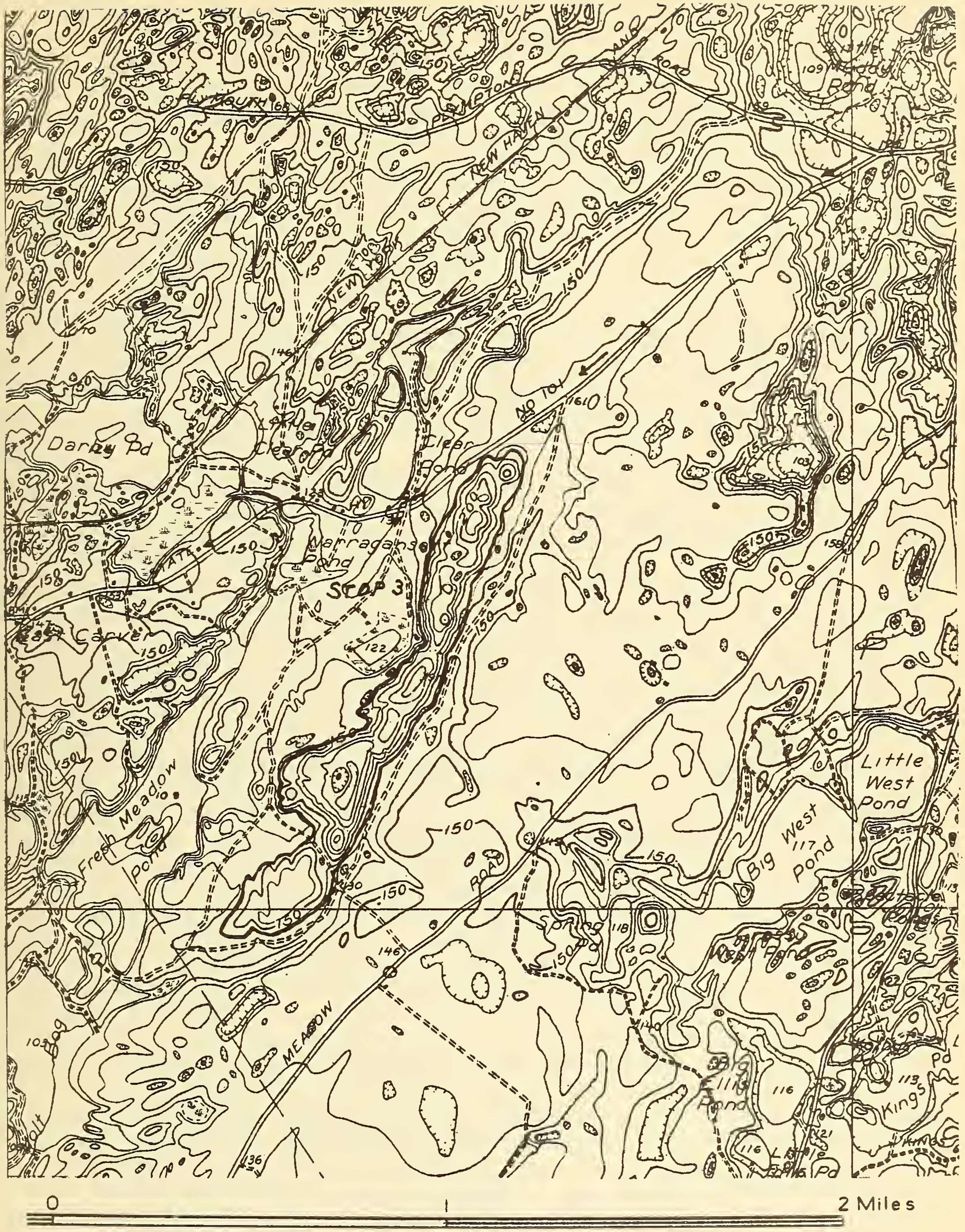
The plain slopes gently toward the southwest and there are many long shallow furrows on its surface, which trend in the same direction. In many places it displays an intricately kettled topography, and elsewhere there are many kettle holes scattered over its surface. Large erratics may be seen on the floors or slopes of several of these hollows, some of which have a definite northeast-southwest elongation. Except for these erratics, the material of which the plain is composed shows a systematic change in texture from northeast to southwest. At the northeast it is chiefly coarse gravel; toward the southwest it becomes sandy gravel and then chiefly sand.

The Carver plain was more or less contemporaneous in origin with the Monks Hill moraine. It was built of outwash material spread southwestward by drainage from the Cape Cod Bay ice-lobe, assisted to some extent by melt-water from the Buzzards Bay ice-lobe which was then standing with its frayed margin along the line marked by the Middleborough kame moraine. That ice, however, had left innumerable blocks of ice on the surface from which it had largely withdrawn. These were covered or surrounded by the glacio-fluvial debris of which the plain was constructed. In addition there were a few drumlinoid hills of glacial till and other patches of ground moraine, left by the Buzzards Bay ice, which were too high to be completely covered by outwash.

38.5 Turn left on sandy lane at signs pointing to "Rod and Gun Club" and "Pinewood Lodge."

38.7 <u>Stop</u> <u>No</u>. <u>3</u>. Middleboro Road crevasse filling.

At this place, a high ridge on the left of the lane extends southwestward from Middleboro Road for a mile and a half and stands 50 to 70 feet above the level of the Carver pitted plain. (Fig. 2) It rises rather abruptly above the plain both along its flanks and at its narrow ends. The top of this ridge is an irregular, undulating surface with knob-like summits that rise to



Contour interval 10 feet

Figure 2

A portion of the Plymouth topographic sheet showing the Middleboro Road Crevasse Filling surrounded by the Carver pitted plain.

altitudes of more than 200 feet and with several small, enclosed depressions. The outline of the west side of the ridge is irregular; its eastern side has been straightened and probably steepened somewhat by the erosion of a furrow on the Carver plain. The furrow was obviously produced by headward erosion of a gulley that was extended northeastward from the northern end of the kettle-hole now occupied by Swanholt Bog. The width of the ridge varies, consequently, from less than one tenth to about one fourth of a mile.

Boulders ranging up to 15 feet in diameter are distributed irregularly over the surface of this ridge. Boulders also occur in a pit excavated on its western side where vaguely stratified beds of sand and gravel dip steeply to the southeast; yet there is no accompanying till. All available information indicates that the ridge is composed essentially of sand and gravel, with a scattering of boulders within the gravel beds and over the surface.

Whatever the origin of the ridge, it must have been formed after the Buzzards Bay ice-lobe had deposited the Hog Rock moraine but before the construction of the Carver plain around it. Its elevation above the plain and the dip of some of its bedding indicate that the ridge is not a part of the plain. While the Hog Rock moraine was being deposited, active ice must have been moving forward from the northwest in a direction approximately at right angles to the ridge. Obviously the ridge could not have survived this forward motion and would have been destroyed had it been in existence at that time. It is too small a feature to have served as an effective barrier which the ice would override, as it did the Pine Hills and Indian Hill. On the other hand, the features of the Kings Pond pitted plain and the Snipatuit kame moraine indicate that during their construction the ice of the Buzzards Bay lobe was practically stagnant in the region northwest of the ice contact slope along the western side of the northern part of that plain, a region that includes the site of the Middleboro Road ridge. It was then that the ridge could well have been constructed, later to be surrounded by the outwash gravels of the Carver plain.

The ridge should probably not be called an esker. It is not shaped like a railroad embankment, its summit is broad, uneven and studded with many small irregular knolls. Furthermore, it is too short for an esker of such dimensions; no continuations of it are present either to the northeast or the southwest. A stream large enough to have built an esker of such dimensions would surely have left its mark over a longer distance.

All observed features of this ridge combine to indicate that it is composed of glacio-fluvial debris piled between confining walls of ice. The trend of the ridge is essentially parallel to that of the Hog Rock moraine, the ice contact slope on the west side of the Kings Pond pitted plain and the elongate kettle holes in that plain. Evidently, then, a huge crevasse parallel to the ice margin, had opened in the almost stagnant ice of the Buzzards Bay lobe as that ice melted away from the inner side of the Hog Rock moraine. Into this crevasse superglacial streams dumped vast quantities of sand and gravel, and many boulders and larger erratics fell as they melted out of the immediately adjacent ice. The abrupt changes in texture from place to place within the ridge and the irregularities of its summit profile are the expected result of such an origin. The small hollows on its top and flanks might result from uneven deposition, but they are more likely true kettle holes formed where chunks of ice fell into the crevasse from time to time and were covered with the meltwater deposits.

This crevasse filling is a unique feature of the entire southeastern Massachusetts region. Although some of the eskers in the Plympton and Snipatuit Pond quadrangles include boulders several feet in diameter, such large stones are mingled with others averaging a foot or so across rather than associated with sand and fine gravel as here. Furthermore, the eskers differ greatly

from the Middleboro Road crevasse filling in both longitudinal extent and profile. In addition the eskers are oriented in directions parallel to the direction of ice movement, not at right angles to that direction, as here.

The preservation of this fairly large feature was possible only if the ice surrounding it, during and after its construction, remained practically stagnant. This portion of the Buzzards Bay lobe therefore disappeared by downwasting of its surface after forward movement of the ice had ceased. Thus the area around the ridge was finally left free of ice except for many isolated remnants of the former continuous sheet around and over which the meltwaters from the still active Cape Cod Bay lobe deposited the materials of the Carver pitted plain.

Turn around and return to Route 44.

38.9 Turn left onto Route 44.

You are now continuing across the northeastern part of the Carver pitted plain. Note the cranberry bogs in kettle holes and the occasional sand pits from which sand is derived for spreading over the bogs.

39.9 Take right fork, leaving Route 44 and entering East Carver.

41.3 About here, you leave the Carver pitted plain and enter the Middleborough kame moraine. The boundary between the two is not well defined at this place. This kame moraine marks the frontal zone of the Buzzards Bay ice-lobe at the time the Carver plain was built.

41.9 Pond in shallow kettle hole on left.

42.0 Cranberry bogs on right.

42.2 Rejoin Route 44 in North Carver.

42.8 Keep right on Route 44 and join Route 58.

43.0 Turn right on Route 58.

43.2 You are now leaving behind the hills and kettles of the Middleborough kame moraine and starting across an area of lower and smoother topography, an area of ground moraine from the Buzzards Bay ice-lobe.

44.7 Cross the Winnetuxet River, a tiny brook.

45.3 Plympton Center.

45.6 Keep straight ahead; Route 58 leaves to the left.

45.7 You are now leaving the ground moraine behind and entering the Plympton kame-field in which you will be for the next 3 miles. Note the great change in topography.

The Plympton kamefield was deposited by the Buzzards Bay ice-lobe at the same time that the Kingston kamefield was being formed by the melting of the Cape Cod Bay ice-lobe. One merges into the other, north of the west end of the Monks Hill moraine.

46.4 Pass end of Crescent Street.

46.6 Cranberry bogs on each side of road. This is the northwest margin of the Plympton kamefield.

46.7 Bedrock nobs at three o'clock.

46.9 Turn right on Ring Road. This brings you well within the kamefield.

47.2 Cross Jones River, at this place a small brook with a pond upstream, to the right, from the road.

48.3 Cross Barrows Brook.

49.1 Cranberry bog at two o'clock with esker beyond it.

49.3 Stop No. 4. Esker (Fig. 3)

49.5 Turn right on Route 106, Wapping Road.

50.7 Cross Jones River again. Note bedrock ledges on left of road and just above the river on its southwest side. (The road here is running northeast.)

51.1 Bear right with Route 106.
You are now on the sandplain that you crossed this morning between 27.5 and 27.9.

51.9 Turn right on Routes 3 and 3A. You were here this morning at 27.8.

52.1 Cross Jones River for the last time.

52.4 Bear right at fork on Route 3, one of Massachusetts' new highways of which Governor Dever is very proud. You are now in the Kingston kamefield again. See notes at 28.0.

53.1 Here you enter the portion of the Kingston kamefield that was modified by over-riding ice as described in the notes at 28.0.

54.0 You are now leaving the Kingston kamefield and entering the Plymouth kamefield. See notes at 34.8. There is no definite boundary between the two.

55.5 Cross over Route 44. You went through this underpass at 35.5.

55.9 Through underpass beneath Summer Street.

57.4 Across overpass above Long Pond Road. Still in the Plymouth kamefield.

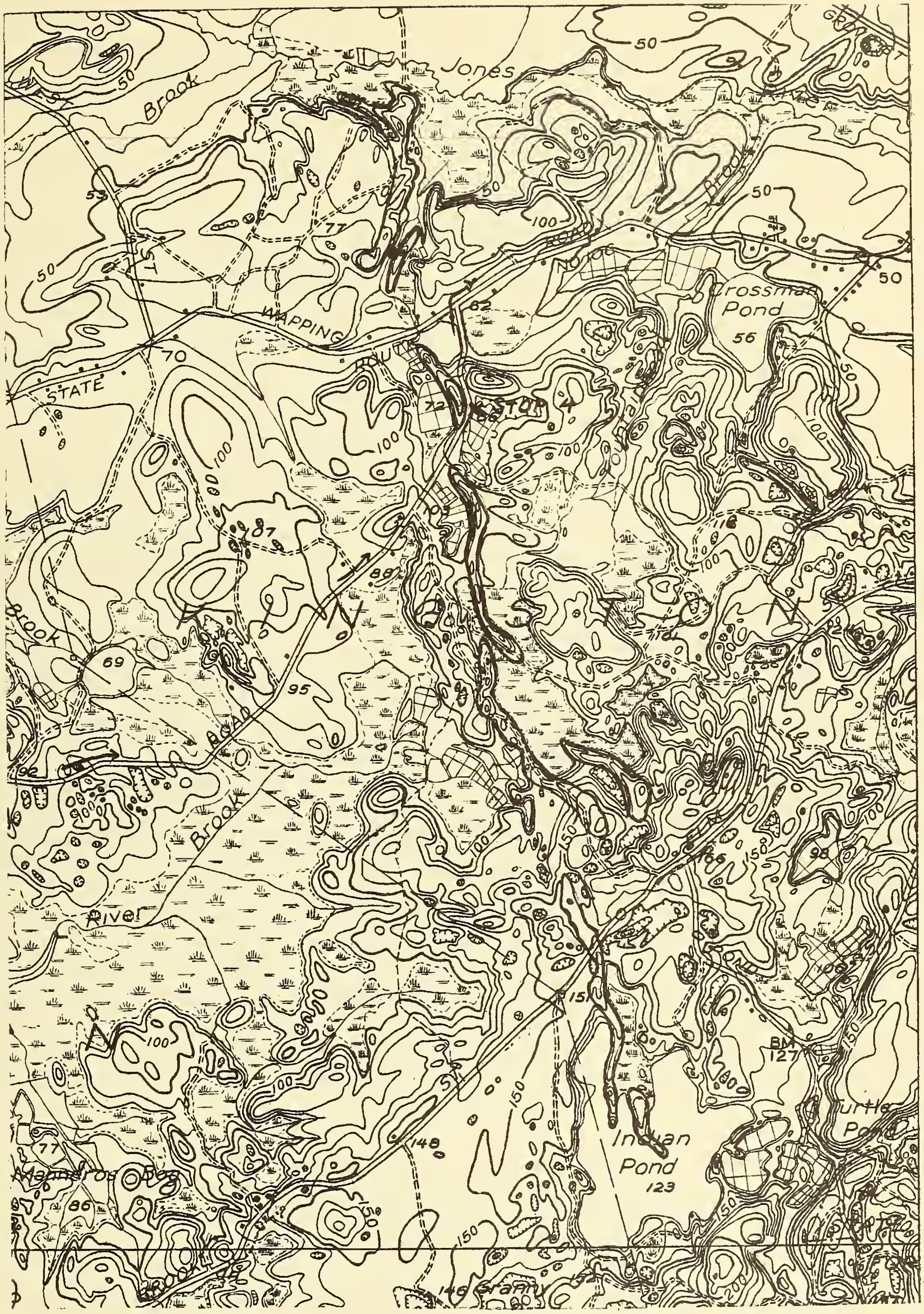
58.9 Pass Sandwich Road.

59.9 Rejoin Route 3A, the old Route 3.
Pilgrim Hotel at the left, on bluff overlooking Plymouth Bay.

60.5 Here you are leaving the Plymouth kamefield and entering an area of ground moraine which veneers the Pine Hills.

Viewed as a whole, Pine Hills is an asymmetrical highland rising to a maximum altitude of 395 feet in Manomet Hill. Its smoothly rounded contour is broken on its gentler western side by several remarkably parallel valleys having a northeast-southwest trend. On the steep eastern side are irregular, nonparallel gulleys with steep gradients that interrupt the continuity of a prominent north-south escarpment.

According to earlier interpretations, these hills were believed to be part of an interlobate moraine, extending southward to include the high,



0 1 2 Miles

Contour interval 10 feet

Figure 3

The northeast corner of the Plympton topographic sheet showing the esker in the Plympton-Kingston kamefields.

knobby ground between Bournedale and Great Herring Pond, and deposited at the same time as the Buzzards Bay and Sandwich moraines. There are, however, many cogent reasons why that interpretation cannot be accepted.

(1) The Buzzards Bay and Sandwich moraines are separated from the Pine Hills by a distance of nearly six miles, at least two-thirds of which is occupied by bedded deposits of the Wareham pitted plain with a surface sloping southwestward.

(2) The northwestern trend of the Ellisville moraine places it directly across the zone that was supposed to represent a north-south trending, interlobate moraine.

(3) The Pine Hills do not display the knob-and-kettle topograpny that ordinarily characterizes an interlobate moraine.

(4) The deposits south and west of Pine Hills (Ellisville moraine, Wareham pitted plain, and kame areas north of them) were formed while ice of the Buzzards Bay lobe lay somewhere in the vicinity of the Hog Rock moraine, nearly 5 miles southwest of Pine Hills. Obviously, the Pine Hills could not, therefore, have been in an interlobate position at this stage in the glacial history.

(5) To have formed the Ellisville moraine, Wareham pitted plain, and Plymouth kamefield, the ice of the Cape Cod Bay lobe must have overriden the whole of the Pine Hills and advanced some distance farther westward and southwestward. (See Plate 1) Therefore, the area west of the Pine Hills must have been uncovered by recession of the Buzzards Bay lobe of ice rather than occupied by it.

Evidently, the advancing ice of the Cape Cod Bay lobe was sufficiently thick so that its upper part sheared over the top of this obstruction and carried large volumes of till and thousands of huge erratics forward to build the Ellisville moraine. As it moved across the Pine Hills, the ice smoothed off irregularities that may have previously marked its topography, spread a veneer of till upon the surface, and deposited hundreds of gigantic granite boulders. Moving onward down the west side of the Pine Hills the ice smoothed that side of the narrow upland and cut the many conspicuous furrows, some of which are several hundred feet wide and a few score of feet deep, that characterize the topography of this slope. These furrows are believed to be comparable in origin to glacial grooves abraded on bedrock ledges. Such large-scale sculpturing of the land over which the ice was advancing is to be expected at this place, because the underlying material was weak, unconsolidated sediments rather than resistant, well-indurated sedimentary rock or firm, crystalline igneous rock. Furthermore, the volume of ice that moved down this slope must have been very great to permit the deposition of the Ellisville moraine, two or three hundred feet high and more than a mile wide, a short distance farther to the southwest, and that ice must have been laden with an abundance of graving tools -- the blocks of rock, boulders and debris that form the moraine.

Several considerations support this conclusion that the valleys on the west side of the Pine Hills upland are glacially-abraded grooves rather than stream-eroded channels. These linear depressions are approximately parallel to one another and trend obliquely rather than directly down the slope. This direction is precisely that of the movement one would expect for the ice advancing to build the Ellisville moraine. The furrows occur only on the lee side of the hills, with respect to ice motion, and they are almost the same width throughout their entire length rather than narrower upstream as would be expected if they were stream-cut. They have broader, more rounded bottoms than would normally be developed by streams having such steep gradients as they display. The upper ends of some of the furrows lie well to the east of the crest of the ridge-like upland, despite the fact that the east slope is much steeper than the west slope and should therefore give a marked advantage

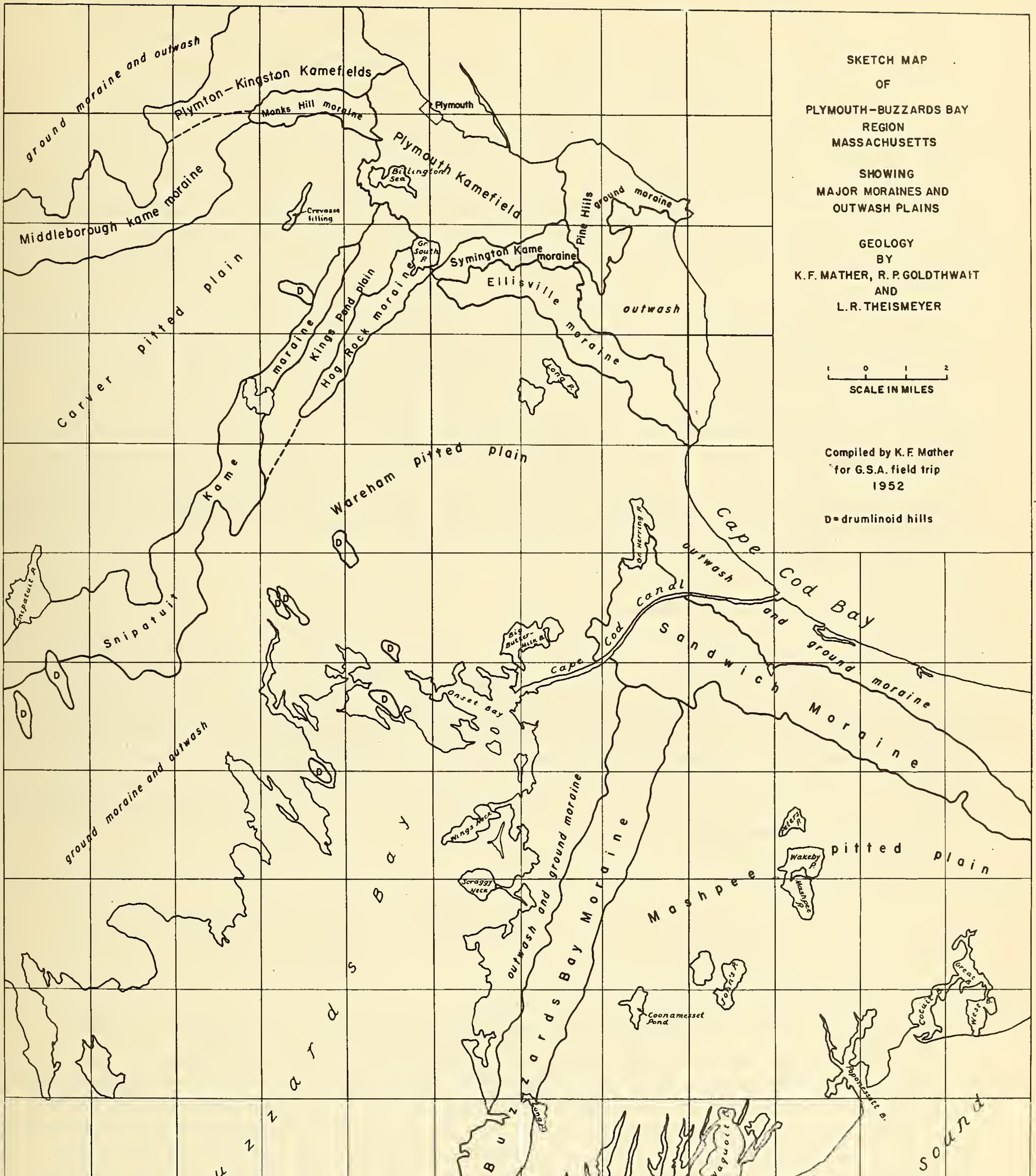

SKETCH MAP
OF
PLYMOUTH–BUZZARDS BAY
REGION
MASSACHUSETTS
SHOWING
MAJOR MORAINES AND
OUTWASH PLAINS
GEOLOGY
BY
K.F. MATHER, R.P. GOLDTHWAIT
AND
L.R. THEISMEYER
SCALE IN MILES
Compiled by K.F. Mather
for G.S.A. field trip
1952
D=drumlinoid hills
ground moraine and outwash
Plymton–Kingston Kamefields
Monks Hill moraine
Plymouth
Plymouth Kamefield
Billington Sea
Crevasse filling
Middleborough kame moraine
Pine Hills
ground moraine
Symington Kame moraine
Ellisville moraine
outwash
Carver pitted plain
Kings Pond plain
Hog Rock moraine
Kame moraine
Wareham pitted plain
Cape Cod Bay
outwash and ground moraine
Cape Cod Canal
Sandwich Moraine
Snipatuit
Onset Bay
ground moraine and outwash
Buzzards Bay
outwash and ground moraine
Buzzards Bay Moraine
Mashpee pitted plain
Wakeby P.
Scraggy Neck
Coonamessett Pond
Waquoit
Vineyard Sound
Nantucket Sound

Plate I

to eastward flowing streams in the competition of headward erosion.

It is therefore believed that the Pine Hills upland was a pre-Mid-Wisconsin ridge, crossed obliquely by the ice of the Cape Cod Bay lobe during the Middle Wisconsin glacial stage while building the Ellisville and all earlier moraines, and sculptured by that ice into approximately its present contours. During recession of the ice, and possibly in small part while the ice front was still advancing, ice-borne debris was deposited more or less evenly over the surface. Thus it seems likely that the veneer of ground moraine covering the Pine Hills is of about the same thickness in the bottom of the furrows as on the rounded divides between them. Post-glacial erosion by subaerial agencies such as slope-wash, wind and wet-weather rills has not greatly changed the landscape since the ice disappeared from this region.

The only exposures of the materials beneath the veneer of ground moraine are found in the bluffs near Rocky Point at the north end of the Pine Hills and near Manomet Point at the east. Here there are outcrops near sealevel of rusty indurated till and tough indurated clayey till with dark brown weathered zones overlain by stratified sand and gravel. This till is very likely much older than that of the ground moraine. It may be equivalent in age to the till of the Iowan substage of the Wisconsin or even to that of the Illinoian glaciation. It is entirely possible that the Pine Hills represent a remnant of a pre-Mid-Wisconsin interlobate moraine. On the other hand, these hills may preserve beneath the mantle of drift a remnant of the Cretaceous or Tertiary sediments of the Coastal Plain series.

62.5 Pass White Horse Beach Road.

63.0 Cross Beaver Dam Brook.

You are now leaving the area of ground moraine and are about to swing southward a mile or more east of the Pine Hills. The area to be crossed is best described as a kamefield, constructed by the downwasting stagnant ice of the Cape Cod Bay lobe on the stoss side of the Hills.

64.5 Fresh Pond, at three o'clock, occupies the bottom of one of the larger kettle holes in this kamefield.

65.9 Cross Indian Brook.

67.0 Leave the kamefield with its glacio-fluvial materials and continue across another area of ground moraine.

69.1 Road to Ellisville Village on the right.

Here you enter the Ellisville moraine at one of its narrowest parts. This moraine extends from the shore of Cape Cod Bay, a half mile east of the road you are on, northwestward to Telegraph Hill (elevation 235 feet), about 4 miles away, and thence continues westward another 3 1/2 miles to Boot Pond.

Like other moraines in this area the Ellisville is composed predominantly of coarse sandy till. The erratic blocks strewn over its surface are more numerous and many are larger than those left by the same lobe of ice farther south in the Sandwich moraine. Angular masses of coarse granite 20 to 30 feet in diameter are rather common near the southern border of the moraine, southwest of Telegraph Hill, and also in its western section near Crooked Pond.

The Ellisville moraine does not stand prominently above the outwash plain that borders it on the south. The transition between moraine and outwash is a zone of severe slumping due to kettle-hole formation, and consequently many places within the northern boundary of the Wareham pitted plain display a moraine-like topography. Despite this the skyline of higher parts of the

outwash area is rather smooth, and there is an abrupt decrease in the number of large erratics as one proceeds from the till of the moraine to the gravel and sand of the outwash plain.

The position and trend of the Ellisville moraine show that most of it must have been deposited by the Cape Cod Bay lobe after this ice had receded northward at least 6 to 10 miles from the Sandwich moraine and while its western portion was moving westward over the high ground of the Pine Hills and Indian Hill. This inference is supported by the northwest-southeast elongation of some of the higher ridges in the eastern half of the moraine, formed presumably by ice that shoved against them from the northeast.

The western end of the Ellisville moraine may, however, have been formed by ice of the Buzzards Bay lobe during its retreat to the position of the Hog Rock moraine and before the gravel of the Wareham pitted plain was spread south of South Pond. A northeast-southwest trend of till ridges in the moraine near Gunners Exchange Pond and a greater concentration of blocks in this vicinity suggest such an interpretation. Abundance of erratics is far more characteristic of deposits of the Buzzards Bay lobe than of the Cape Cod Bay lobe. Furthermore, the whole moraine turns southwestward in its western mile and a half. Such a change in trend might have occurred of course, because a tongue of the Cape Cod Bay ice shoved farther to the southwest in this district than elsewhere along the moraine. But this seems unlikely because the ice that could thus reach that locality probably must have moved over higher parts of the Pine Hills, and this would have impeded its progress.

69.6 Leave Ellisville moraine and start across the eastern part of the Wareham pitted plain. This plain slopes upward from sealevel at Buttermilk Bay and at the Wareham River estuary to altitudes of more than 240 feet in one apex southwest of Gunners Exchange Pond, of more than 250 feet in another apex south of Crooked Pond, and of more than 230 feet in a third apex east of Mast Road in the southeastern corner of the Plymouth quadrangle. The average surface slope of its smoother parts varies from 15 to 30 feet per mile. Gradient calculations across remnants of the plain at several places show that in general its original surface before the development of kettles was slightly concave upward.

The Wareham pitted plain was accumulated as a subaerial compound fan of outwash in a reentrant between the two ice-lobes. Although both lobes doubtless contributed material to its construction, the drainage from the northeast may have persisted longer and certainly dominated the construction of at least the upper part of the plain. This is evident from the southwesterly slope of nearly all flattish remnants of the plain, emphasized by the trend of subaerial furrows on its surface; from the southwestward decrease in grain size of the materials; and from the southwest inclination of the layers of sand and gravel, approximately parallel to the surface except where the bedding is locally channeled and crossbedded. In general, there is a gradual decrease in size of the constituents from coarse gravel with rounded boulders, some of which are as much as three feet in diameter, near the Ellisville moraine, to fine sand and silt near Agawam River and Buttermilk Bay. It is probable, however, that drainage from the Buzzards Bay lobe was also southwestward along the ice-front because the underlying land sloped in that direction. Such a condition would help to account for the lack of marked apices of the plain along its northwest side and for the dominant southwestward slope of its surface and bedding.

Wind-cut stones or ventifacts are more abundantly scattered over the northern half of the Wareham pitted plain than anywhere else in this region. Absence of aeolian sands in the kettles shows that wind abrasion could not have been effective after the buried ice disappeared. In general, a larger

percentage of the ventifacts in this area have escaped modification since they were formed than was true of those found farther southeast on western Cape Cod; the facet edges on many of them are sharp, and more of them have preserved a high original luster. It would appear plausible, therefore, that the differences in perfection of the wind-sculptured stones in the Wareham and Mashpee pitted plains reflect a difference in the length of time since they were formed. The difference in time between the construction of the Mashpee pitted plain and that of the Wareham pitted plain was probably no more than three or four thousand years, if it was even that long. If these inferences be true, we have at least a qualitative measure of the degree of obliteration and modification of wind-cut surfaces by weathering during such a relatively short interval of time.

71.0 Take right fork toward Cedarville, leaving Route 3.

72.0 - 73.3 Great Herring Pond, occupying one of the largest ice-block holes in the Wareham pitted plain, on the right.

72.9 Leave Wareham pitted plain and enter the Sandwich moraine near its northwestern end. As shown on Plate 1, this moraine stretches for many miles to the southeast and forms the "backbone" of Cape Cod.

74.2 Turn sharp right toward "Head of Bay."

74.8 Turn sharp left to Fire Tower.

75.1 <u>Stop</u> <u>No</u>. <u>5</u>. Fire Tower.
The panorama from the outlook platform at the top of the tower includes the head of Buzzards Bay, toward the southwest, and the full length of Cape Cod Canal from that bay to its other end in Cape Cod Bay, due east from the tower. Signal Hill, on which the tower stands, is the highest of the many irregular hills near the west end of the Sandwich moraine which stretches away toward the eastsoutheast. The Buzzards Bay moraine runs southward from the west end of the Sandwich moraine, as shown on Plate I. The apex of the Mashpee pitted plain is in the angle formed by the two moraines. To the west, beyond the edge of the Sandwich moraine (0.6 miles due west of the tower), you may look across the wide expanse of the Wareham pitted plain.

75.1 Retrace the route to Herring Pond road.

75.9 Keep straight ahead on Herring Pond road at fork (74.2).

76.0 Turn right toward Buzzards Bay.

76.1 Curve right onto Route 6, paralleling Cape Cod Canal.
You are still in the Sandwich moraine but it is considerably modified here by the excavation of the canal.

77.9 About here you leave the moraine and enter the Wareham pitted plain.

78.6 Traffic circle at end of Bourne Bridge. Keep right and continue up the ramp to the Bridge on Route 28.

79.2 Cross Cape Cod Canal on Bourne Bridge.

79.6 Traffic circle, keep south on Route 28.

Note the ice-contact slope on the left, roughly parallel to the canal. Use Figure 4 as a route map for the next few miles. The Buzzards Bay moraine is on the left of your route and you are traversing an area of glacio-fluvial deposits, deposited largely by melt-water from the Cape Cod Bay ice-lobe.

As the thick, active ice of the Buzzards Bay lobe melted back from the Buzzards Bay moraine, a long, low depression sloping southwestward was uncovered between the western side of the moraine and the ice front (Fig. 4). The Cape Cod Bay lobe was still building the Sandwich moraine. Part of its meltwater, unable to escape through the high western part of the moraine onto the high apex of the Mashpee pitted plain, found an outlet southward along this trough. Sand and gravel deposits from that drainage now cover most of the surface from the vicinity of the Bourne Bridge southward through Pocasset, Cataumet, and North Falmouth to West Falmouth.

The belt of lower ground along which much of this meltwater escaped was littered with masses of stagnant ice that had been left by the Buzzards Bay lobe. Many of the ice-blocks did not melt away to form kettles until after the drainage from the north had ceased. Here and there between these blocks of ice were kames and bouldery knobs of till, some of which still protrude above the later glacio-fluvial deposits. Over the lower surfaces between the blocks of ice and these depositional hills a veneer of outwash was spread from the northwest.

The meltwater from the Cape Cod Bay lobe spread along many shifting channels that formed a complicated braided pattern, as the streams found their way around obstructions and moved over the uneven land surface already floored with loose debris. Water may have been ponded for a time against obstructions of stagnant ice or hillocks of till. Material washed into such temporary pools would form small deltas with steeply-inclined stratification. Gradually the outwash materials from the north blanketed the earlier deposits and a smooth plain of sand and gravel, sloping southwestward, was formed in the shape of a very narrow, partly-opened fan. On the north its high apex was banked against and into the Sandwich moraine; its western side lay against the frayed margin of the ice sheet, and its eastern one against the Buzzards Bay moraine. The outer, convexly-curved margin of the fan lay somewhere out in what is now Buzzards Bay.

Only parts of the original sloping surface remain today, because the plain was indented by many kettle-holes and by gullies produced by later erosion. The highest and largest of the remnants comprises a few hundred acres, 110 to 130 feet above sealevel, east of the traffic circle at the southeast end of the Bourne Bridge. Southwestward from the bridge toward Pocasset many smaller gravel deposits with smooth, gently sloping tops rise to altitudes of about 100 feet. Gravel knobs between Pocasset and State highway, Route 26, attain altitudes of 70 or 80 feet, and three miles farther southward in Megansett and North Falmouth the smooth tops of similar deposits have altitudes of only about 50 feet. Still farther south, narrow plains of gravel between Crocker Pond and West Falmouth lie only 20 to 25 feet above the level of Buzzards Bay.

Pebbles of types of rock which have been found in the Sandwich moraine, but not in the Buzzards Bay moraine, have been noted at a number of places in the gravels of the plain. For example, the chips of black and white laminated slate that are found almost everywhere in the Sandwich moraine are common in the gravels around Beaton Bog in South Pocasset, but in the Buzzards Bay moraine only a few hundred yards away there are none of these chips. Pebbles of the same type were noted also at other pits in the area between the moraine and Buzzards Bay. These stones are a further indication that the materials composing the plain were spread southwestward from the Cape Cod Bay lobe.

83.7 Traffic circle. Keep straight ahead on Route 28.

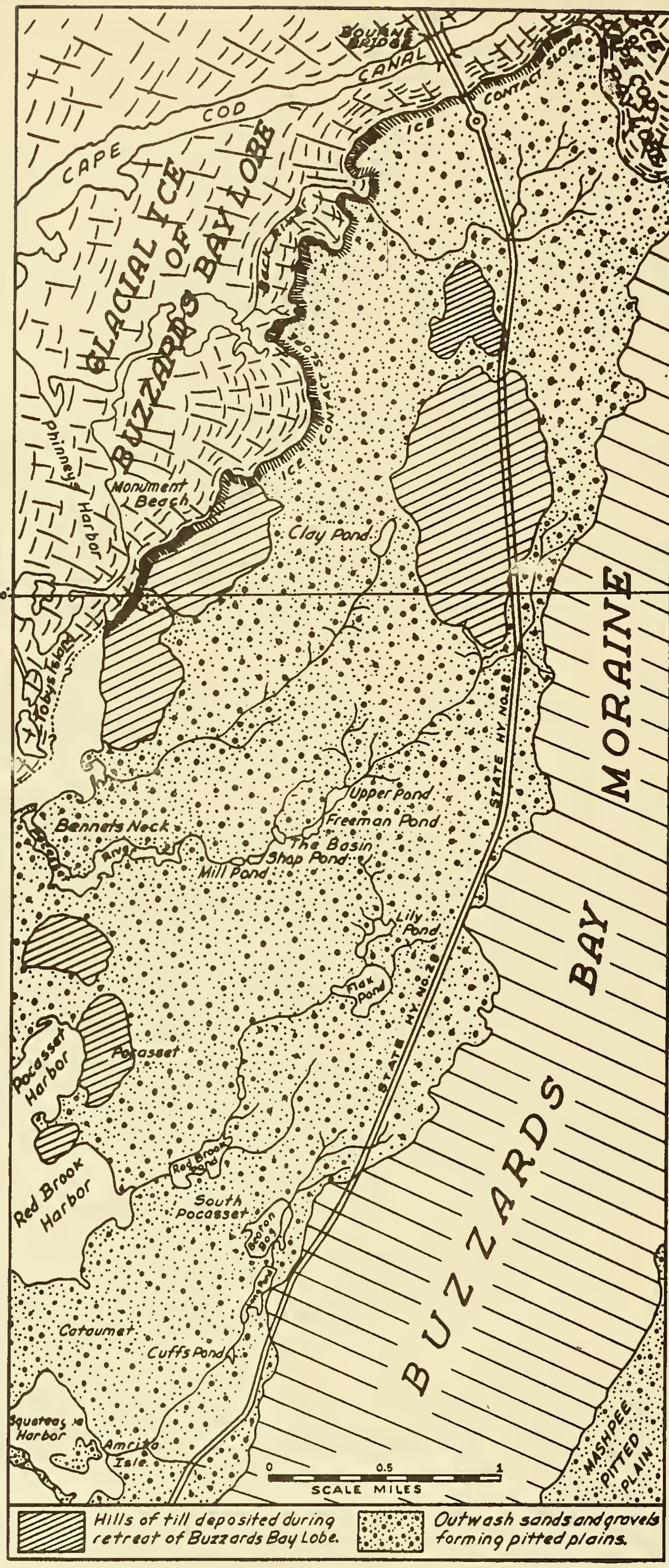


FIGURE 4

SKETCH MAP OF PART OF POCASSET QUADRANGLE SHOWING PRESENT DRAINAGE IN AREA OF GRAVEL FAN THAT WAS DEPOSITED BETWEEN THE BUZZARDS BAY MORAINE AND THE BUZZARDS BAY ICE LOBE IN A POSITION OF ITS RETREATAL STAGE.

84.3 Cranberry bog on right. For next 0.7 mile the highway is just within the edge of the Buzzards Bay moraine.

84.9 Long Pond, on right, occupies a kettle hole in the glacio-fluvial deposits close to the boundary between them and the Buzzards Bay moraine. Opposite the southern end of this pond the road crosses that boundary and continues on the glacio-fluvial materials.

86.7 Turn left from Route 28 on Route 151, the Hatchville Road. You are now in North Falmouth.

87.1 Enter Buzzards Bay moraine. You will be in this moraine for the next mile.

88.2 Leave Buzzards Bay moraine and proceed across Mashpee pitted plain.

88.3 Road intersection. Keep Route 151.

88.5 Stop No. 6. Brief pause for consideration of relations between Buzzards Bay moraine and Mashpee pitted plain. Then continue straight ahead on Route 151.

89.0 Road descends to cross one of the furrows on the surface of the Mashpee pitted plain. (Mather, Goldthwait and Thiesmeyer, 1942, pp. 1151-1163)

89.2 Road climbs up from the furrow to the surface of the plain.

89.6 Turn right, leaving Route 151, in Hatchville.

89.9 Turn sharp right and skirt the rim of one of the larger pits in the Mashpee pitted plain, occupied by a cranberry bog, immediately below the road on the left, and Coonamessett Pond, a little farther away.

91.4 Rejoin Route 151 at intersection crossed earlier at 88.3. Continue on 151, retracing our route back to the Bourne Bridge.

93.0 Turn right onto Route 28.

100.5 Cross Cape Cod Canal on Bourne Bridge.

101.1 Traffic circle, keep Route 28, which is here joined by Route 6.
You are now on the Wareham pitted plain again. The road by-passes the village of Buzzards Bay which is on the left.

102.5 Cross bridge; Big Buttermilk Bay on right, head of Buzzards Bay on left.
Continue across Wareham pitted plain with its ponds and cranberry bogs in shallow pits. Surface of plain is here between 15 and 25 feet above sea-level.

105.7 Keep right on Route 28 in East Wareham; Route 6 leaves to the left.

108.2 Cross outlet of Parker Mill pond, which is on right; this is the head of Wareham River which widens downstream on the left.

108.3 Road begins a broad curve to the right and climbs up a gentle slope from the Wareham pitted plain to continue at an elevation above 50 feet on a long oval body of ground moraine oriented parallel to the direction of movement of the Buzzards Bay ice-lobe.

109.5 Leave ground moraine and continue over northwest part of Wareham pitted plain.

110.1 Hill of ground moraine rises 30 feet above road and plain at the right.

111.6 Five Corners; keep Route 28; Route 58 runs north.

112.1 - 112.7 Cross Snipatuit kame moraine. Continue, mostly on ground moraine, to

124.5 Middleboro circle. Keep right on Route 28 to Boston.

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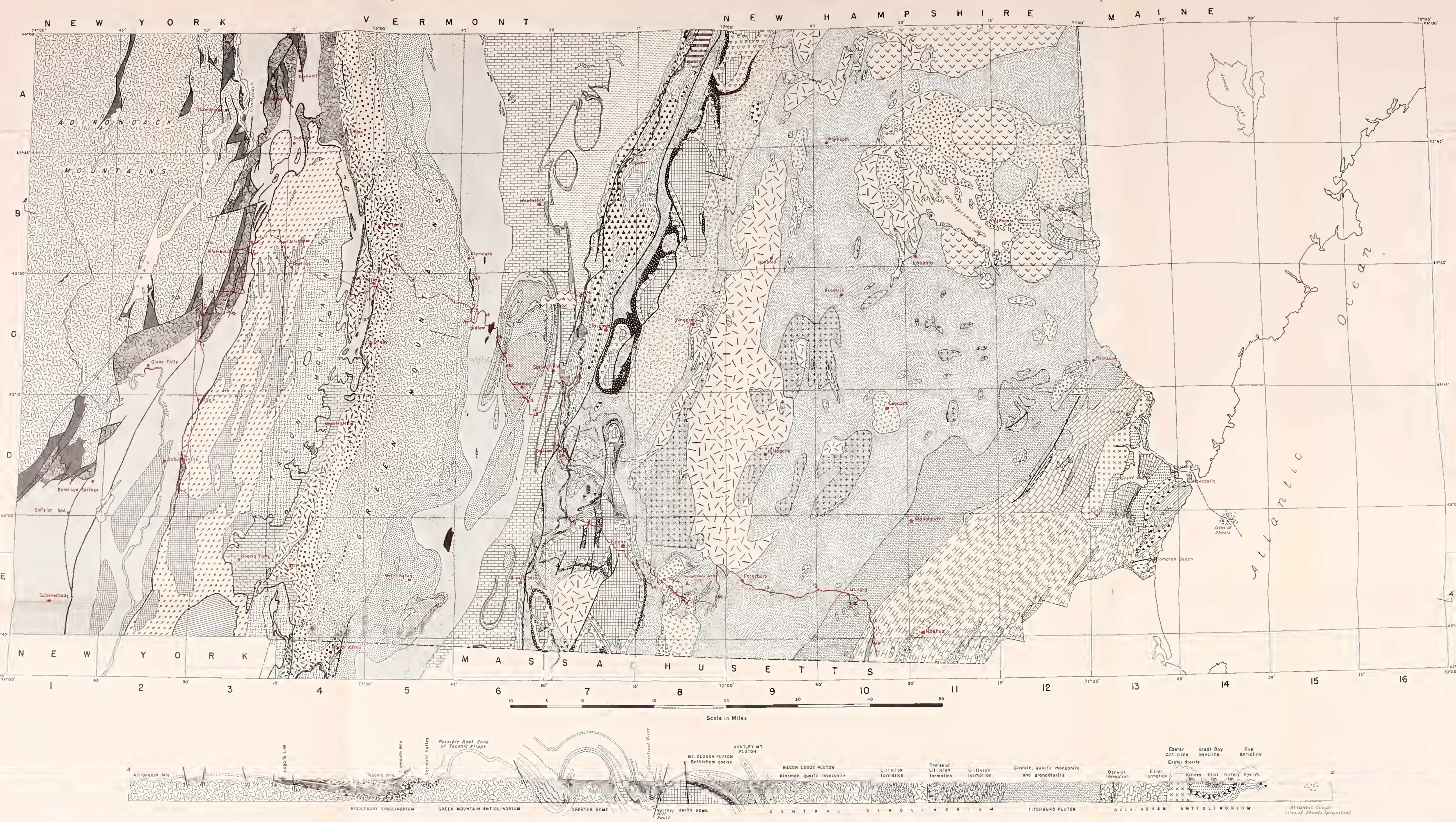

SECTION A-A′

GEOLOGY OF EAST-CENTRAL NEW YORK, SOUTHERN VERMONT AND SOUTHERN NEW HAMPSHIRE